THE TEMPERATURE DEPENDENCE OF FIELD CURRENTS

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Abstract

The increase in the field current observed by Millikan and Eyring to take place at about 1000°K is shown to be of the order of magnitude of the thermionic emission to be expected from a thoriated filament at this temperature. The author considers that the results of Millikan and Lauritsen are inconclusive and do not definitely establish the existence of a dependence of field currents upon temperature. The author has carried out new experiments using an improved method of investigation and has been unable to detect any temperature variation in the field current. His contention is not that no temperature variation exists but that no real variation has yet been observed.

All investigators[1] are agreed that from 80°K to 1000°K the auto-electronic, or field, emission is independent of temperature. There is however a difference of opinion about the existence of a temperature dependence above 1000°K. Millikan and Eyring[2] observed an increase in the emission at this temperature but, by separating out the thermionic from the field current in a mixed emission, I found[3] that the field current showed no systematic increase with temperature and therefore concluded that the increase observed by Millikan and Eyring was due to the occurrence of a thermionic emission. Millikan and Lauritsen[4] have recently stated that the increase in emission observed by Millikan and Eyring "is about a billion times too large to be so interpreted;" this statement is evidently based on the emission characteristics of pure tungsten and disregards the fact that Millikan and Eyring used thoriated filaments. The thermionic emission from a thoriated tungsten filament is in fact of the order of magnitude of the increase observed by Millikan and Eyring, as may be seen from the following considerations.

The Results of Millikan and Eyring

The diameter of the filament used by Millikan and Eyring was 0.00123 cm. Its length is not stated but from the relative dimensions in their diagram it appears to have been of the order of 5 cm, giving a surface area of 0.019 cm.[5]

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[1] J. E. Lilienfeld, Ber. d. Sächs. d. Wiss. **72,** 31 (1920). B. S. Gossling, Phil. Mag. **1,** 609 (1926). R. A. Millikan and C. F. Eyring, Phys. Rev. **27,** 51 (1926).

[2] R. A. Millikan and C. F. Eyring, Phys. Rev. **27,** 51 (1926).

[3] N. A. de Bruyne, Proc. Cambs. Phil. Soc. **24,** 347 (1928).

[4] R. A. Millikan and C. C. Lauritsen, Phys. Rev. **33,** 598 (1929).

[5] S. Dushman, Gen. Elect. Rev. **26,** 156 (1923).

Thermionic emission from a fully thoriated wire at 1100°K is[5] 2.51×10^{-6} amps per cm^2 corresponding to an emission of 4.77×10^{-8} amps from an area of 0.019 $cm.^2$ The Schottky effect at a field of 0.7×10^6 volts per cm would increase the thermionic emission to 1.35×10^{-6} amps; at this field Millikan and Eyring observed an increase in the emission of 0.02×10^{-6} amps. At a field of 1.0×10^6 volts/cm the thermionic emission would be 2.58×10^{-6} amps while the observed increase was 3.0×10^{-6} amps. The thermionic emissions have been computed for a fully thoriated surface, but taking into account the uncertainties in the measurements the observed increases appear to be of the order of magnitude of the possible thermionic currents, even if the surface were not completely thoriated. The experiments of Millikan and Lauritsen do not therefore establish the existence of a dependence of the autoelectronic emission on temperature.

The Results of Millikan and Lauritsen

Millikan and Lauritsen[4] have recently published some new data in which proper allowance can be made for the thermionic emission taking into account the Schottky effect. Unfortunately the new data are limited to one graph in which only two points are relevant. Up to 800°K the current was constant at 4.6×10^{-8} amperes, at 1130°K (a temperature at which the thermionic current was negligible) the current was 5.6×10^{-8} amperes, at higher temperatures a thermionic current set in. These results therefore show a temperature variation which cannot be explained as due to a thermionic emission. Yet the position as left by the publication of Millikan and Lauritsen's paper is far from satisfactory, since it is impossible to have any confidence in a conclusion based on a few measurements of an effect in which it is extremely difficult to obtain reproducible results.

Author's First Results

I first repeated Millikan and Lauritsen's experiment. A constant voltage was applied to a tube and the filament temperature was raised and lowered rapidly in fixed steps, the emission being noted at each step. The voltages used varied between 12,000 and 23,000 volts. A number of experimental runs were carried out. The results were quite inconclusive; two showed an increase in the autoemission at 1100°K of the order of magnitude observed by Millikan and Lauritsen, one showed a decrease in the emission, but the majority gave a series of widely scattered points through which it was impossible to draw any smooth curve; in general the spontaneous fluctuations in the emission were found to be of the order of magnitude of the increase observed by Millikan and Lauritsen. In plotting characteristics showing the variation of emission with field these fluctuations are far less disturbing because of the tremendous increase in the current produced by a comparatively small rise of field, but in an experiment such as this where the field is kept constant the spontaneous variations become relatively important. It was obvious that a new method of attack was required, and it was decided to obtain a continuous record of the galvanometer deflection.

Results by Improved Method of Investigation

The author observed that in some tubes the filament changed its shape considerably when heated and that such distortion was accentuated when a strong field was applied. The same difficulty has been noted by I. Langmuir and K. H. Kingdon[6] in their work on contact potentials. The author therefore used tungsten wire of 0.02 mm diameter instead of the finest wire available. The filament of length was formed into a stable sharp angled loop inside a cylindrical anode closed at one end. The filament leads were encased in glass leaving only the filament exposed. The tubes were exhausted under the same conditions as a transmitting valve, the filament was outgassed and the anode was kept at bright red heat for twenty minutes before sealing off. After sealing off the filament was lit for some time with an applied anode voltage of 10,000 volts.

The galvanometer deflection was recorded photographically on a rotating drum which revolved once in about two minutes. A constant voltage from a valve rectifier set was applied to the experimental tube and the filament temperature was raised, for periods of about ten seconds, from room temperature to some other higher temperature which was fixed for each run. The periods when the filament was hot were recorded on the drum by the lighting of a small lamp which left a trace on the photographic paper. A calibration and zero line were also recorded. In all the curves the time axis increases from right to left.

Fig. 1. Galvanometer record. Applied potential 5,500 volts, filament heating current 0 and 0.235 amp.

Fig. 1 shows the record obtained when the voltage was too low to produce an autoemission. The small regular rises in the emission correspond to the periods when the filament temperature was raised to 0.235 amps [giving a temperature of 1600°K approximately]; 5500 volts were applied to the anode. It will be seen that at 5500 volts a measurable thermionic emission begins at a filament current of 0.235 amps.

Figs. 2, 3, 4, 5 show results obtained with an applied potential of 17,800 volts (corresponding to a field strength of 1.4×10^6 volts per cm). The first signs of any correlation between the emission and the periods of heating occur between a filament current of 0.220 and 0.230 amps. i. e. between 1550°K and 1600°K; it is in just this temperature range that a thermionic current is to be expected.

Figs. 6, 7, 8, 9, 10 show results obtained at an applied potential of 14,800 volts corresponding to a field of 1.2×10^6 volts per cm. Here again the first signs of any increase occur when the filament current is raised to 0.230 amps, corresponding to a filament temperature of 1590°K. Thus no measurable

[6] I. Langmuir and K. H. Kingdon, Phys. Rev. **34,** 129 (1929).

increase in the autoemission takes place up to about 1600°K at which temperature a thermionic emission sets in.

It seems probable that the electrons pulled out by strong fields must come in the main from energy levels lower down than those from which the ther-

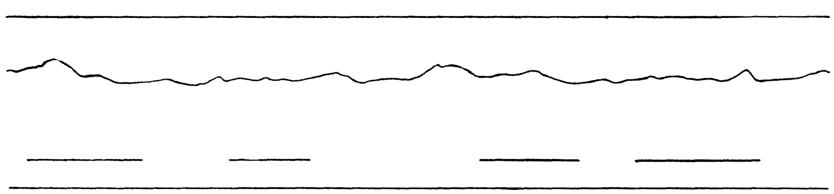

Fig. 2. Filament heating current 0 and 0.190 amp.

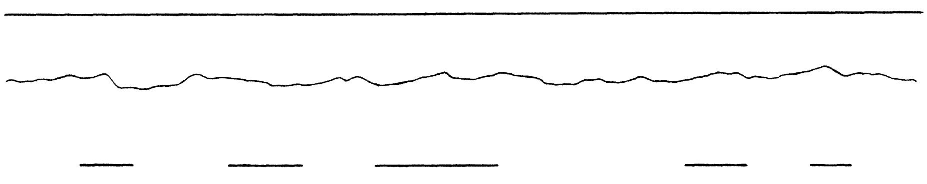

Fig. 3. Filament heating current 0 and 0.200 amp.

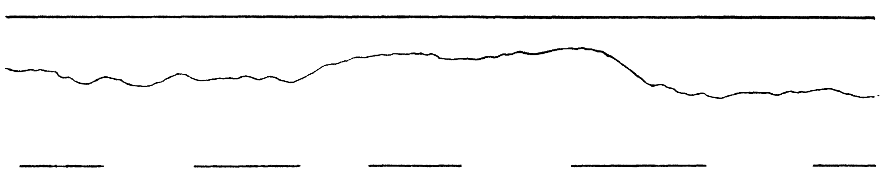

Fig. 4. Filament heating current 0 and 0.220 amp.

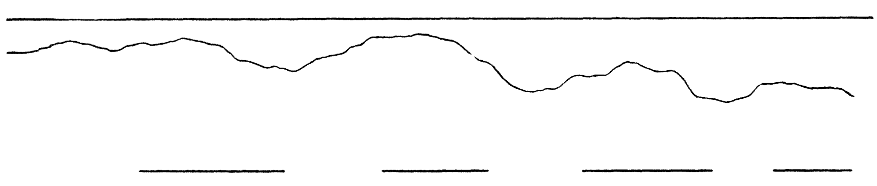

Fig. 5. Filament heating current 0 and 0.231 amp.

Figs. 2, 3, 4, 5. Galvanometer records with 17,800 volts applied to filament. The top horizontal line represents a current of 2 microamperes, the irregular line gives the electronic emission, the broken lines the periods of heating the filament, and the bottom line the galvanometer zero.

mionic emission takes place, since within the limits of experimental error the autoemission is independent of temperature. Unfortunately Sommerfeld's theory can give no information on the temperature dependence, beyond showing that it must be small, since no exact measurement of the applied field is yet possible.

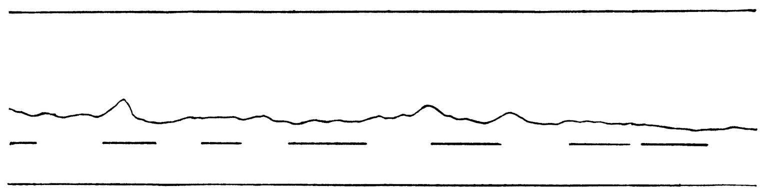

Fig. 6. Filament heating current 0 and 0.195 amp.

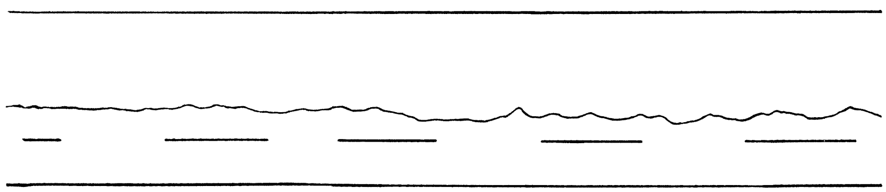

Fig. 7. Filament heating current 0 and 0.202 amp.

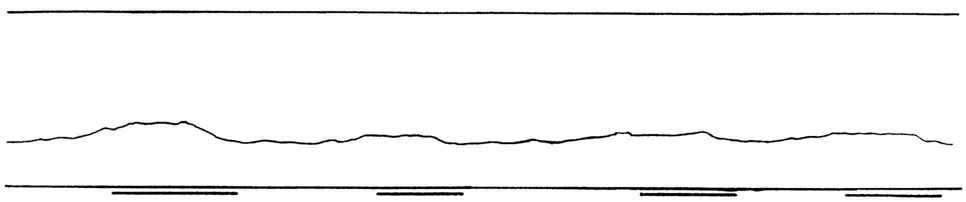

Fig. 8. Filament heating current 0 and 0.230 amp.

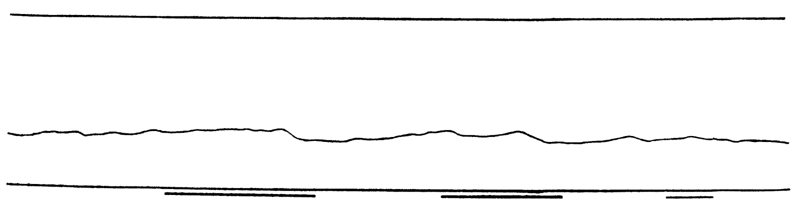

Fig. 9. Filament heating current 0 and 0.235 amp.

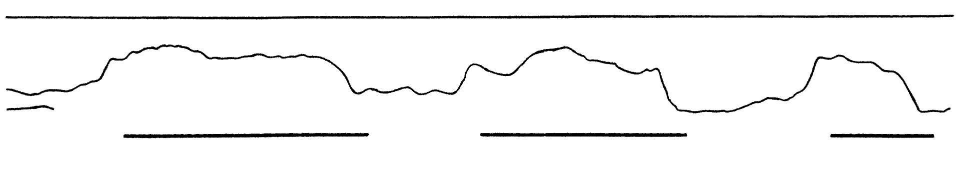

Fig. 10. Filament heating current 0 and 0.248 amp.

Figs. 6, 7, 8, 9, 10. Galvanometer records with 14,800 volts applied to the filament. The top horizontal line represents a current of 2 microamperes, the irregular line represents the electronic emission, the brken lines the periods of heating of the filament, and the bottom line the galvanometer zero.

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