Secondary Emission of Electrons from Complex Targets*

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Secondary emission of electrons from complex targets formed by the condensation of some substances on others has been investigated. The change in the secondary emission with the primary energy appears to be dominated by the overlying element in the low energy range and by the base metal in the range of high primary energies. The total secondary emission in certain ranges may be less or greater than that obtained from either constituent of the complex target when used alone.

THE writer[1] has made studies concerning the general form of the curves obtained when the magnitude of the secondary emission is plotted against the energy of the primary electrons. The correlation of secondary emission with atomic number suggested that complex targets (formed by the condensation of thin films of some substances on others) might show the properties of the superficial layer for primaries of low energy and the properties of the base material for primaries of higher energy.

The apparatus and procedure used for measuring the ratio of the secondary emission to the primary current was of the usual type. The geometry of the arrangement is shown schematically in Fig. 1. A metal plate, T, was inserted to act as a target, and provision was made to control the evaporation of some material from the filaments F and F' a part of which recondensed on this target. In practice the collector of the secondaries, C, was made about 100 volts positive with respect to the target. The net currents to the target and collector were measured. The ratio, R, of the secondary current to the primary current was obtained through division of the collector current by the sum of the collector and target currents.

The first results were obtained from targets formed by a deposit of platinum on aluminum. The tube was evacuated and baked for several hours at about 450°C. Before evaporating any of the platinum, the secondary emission of the aluminum was obtained as a function of the primary energy. Curve 1 of Fig. 2 shows these results. In this figure the abscissas represent the energy of the primary electrons in volts and the ordinates are the common logarithms of the corresponding ratios, R. After curve 1 was obtained, the platinum filaments were heated by an electric current to such a temperature that appreciable evaporation of the platinum took place. After several minutes of this evaporation, the platinum was allowed to cool, and the secondary emission from the target was again measured as a function of the primary energy. The first result of the condensation of platinum on the aluminum appeared to be a lowering of the secondary emission a few percent throughout the entire range of primary energies used. After several such stages of platinum evaporation, curve 2 was obtained. Depositing still more platinum on the aluminum resulted in the curves labelled 3, 4, 5 and 6 (taken in this order although separated in general by data omitted here).

The first result of depositing platinum on aluminum is to decrease the secondary emission a few percent throughout the entire range of primary energies used. As the film thickness is increased, however, the emission for the lower primary energies shows a variation more and

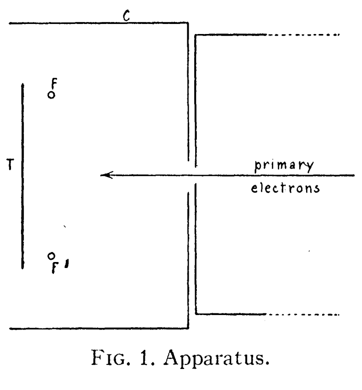

FIG. 1. Apparatus.

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* The material in this paper was obtained in the George Eastman laboratories at M. I. T. and was presented before the Washington Meeting of the Am. Phys. Soc., April 28, 1934. Phys. Rev. **45**, 763 (1934).

[1] Copeland, Phys. Rev. **46**, 167 (1934).

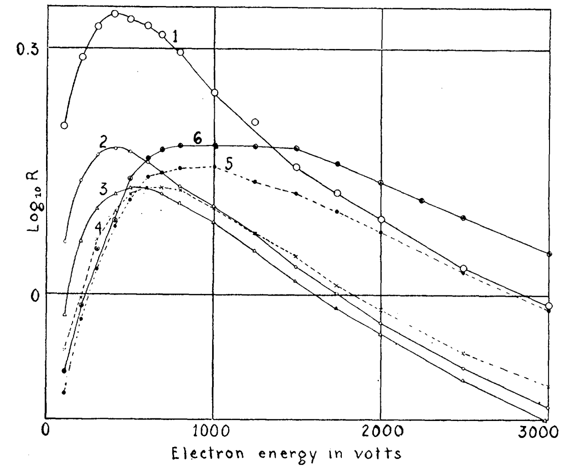

FIG. 2. Platinum on aluminum.

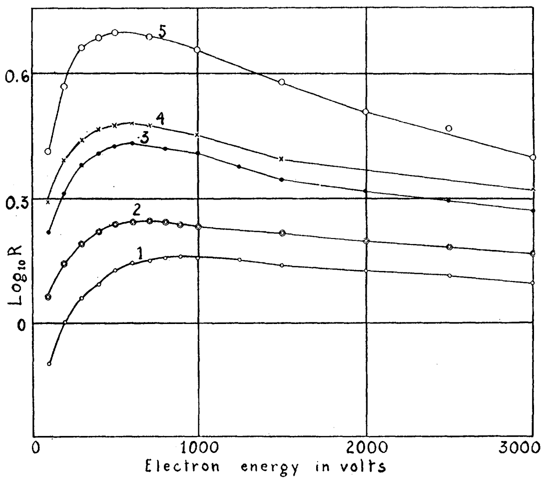

FIG. 3. Calcium on gold.

more characteristic of the platinum, while at higher energies the rate of variation of the secondary emission is certainly characteristic of the aluminum. For the thickest of the platinum films (estimated to be about 7.5×10^{-6} cm thick) for which results are shown by curve 6, the results are very similar to those obtained from thick plates of platinum for primary energies less than 1500 electron volts, while for higher primary energies the secondary emission decreases at a rate characteristic of aluminum rather than platinum.

The most striking fact is that the total secondary emission obtained from a complex target may differ from that obtained using either of the constituent elements, and that it is not a weighted average of the two. For intermediate film thicknesses (curves 3, 4 and 5) the secondary emission is lower than that obtained either from a simple aluminum target or from a simple platinum target over the whole range of high primary energies.

The converse of this case is obtained by depositing a film of calcium on a gold target. (The experimental arrangement was similar to Fig. 1. The target, *T*, was a gold plate and the platinum filaments were replaced by a small spiral of tungsten wire containing the calcium metal.) The result obtained from the gold target after very limited heat treatment is shown by the first curve of Fig. 3. The evaporation of a small amount of calcium a part of which is deposited on the gold, raises the emission a few percent throughout the entire range of energies used. Results obtained with the thicker films (curves 3, 4 and 5) show that the emission increases more rapidly at low energies than it does for the simple gold target. Curves 3 and 4 show that the emission begins to decrease more rapidly than it does for the simple gold target. For both of these curves the slope changes at about 1500 volts and the rate of decrease in the secondary emission beyond this point is quite similar to that obtained from clean gold. Depositing still more calcium on the gold results in the maximum being shifted to lower primary energies as shown by curve 5. The rapid decline of the secondary emission characteristic of calcium then continues to a primary energy in the order of 2000 volts.[2]

Results similar in general nature were obtained for lithium on tantalum and for germanium on gold.

A very interesting result was obtained by condensing the vapor of an ordinary motor oil onto a gold base. Fig. 4 represents the results obtained. The first effect (as before) is an increase in the secondary emission. For intermediate film thicknesses (shown by curves 4 and 5) the secondary emission rises to a maximum in the region at which the earlier work has shown a maximum for surfaces dominated by grease contamination. For curve 5 the rate of decline of

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[2] The results are probably influenced by some degree of alloying. After the removal of the target, inspection revealed that the part of the target on which the primary electrons were incident showed coloring which differed from other parts of the surface.

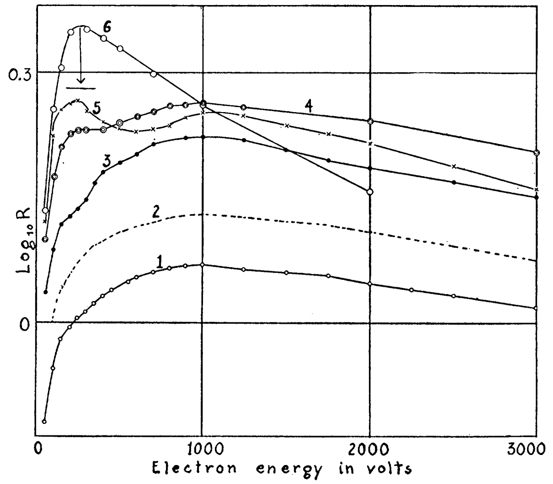

FIG. 4. Oil on gold. Note: All ordinates of curve 6 should be lowered as indicated.

secondary emission just above the maximum is characteristic of the superficial layer. At primary energies slightly higher, the secondary emission again increases and comes to a second maximum at a primary energy quite close to that at which a maximum emission is obtained from the gold alone. The appearance of the double maximum is quite striking, and it suggests the dominance of the overlying film at low energies and the dominance of the base metal at high energies in determining the rate at which the secondary emission changes with the energy of the incident electrons. Fig. 4 is a complete converse of Fig. 2. The emission is raised instead of lowered, and for intermediate film thicknesses, the total secondary emission is greater throughout the entire high energy range than it is for either the simple gold target or for a thick film of the overlying substance.[3]

The films used in these experiments are relatively thick. The work function would hardly be expected to change after the addition of the first few atomic layers. The major portion of the changes in secondary emission must be ascribed to some other cause. The results suggest that the depth to which the primaries penetrate is the controlling factor. This naturally alters the distance through which secondaries diffuse in reaching the surface. These experiments can best be understood on the hypothesis that for a certain primary energy electrons scattered from the primary beam at a certain depth below the surface are more effective than any others in the production of secondaries. This optimum depth varies with the material and with the primary energy. Placing a relatively good scattering agent at the optimum depth naturally increases the secondary emission. Conversely, if at the optimum depth a relatively poor scattering agent is placed, the emission from the surface is reduced. On this basis a complex target may have a total secondary emission in some energy ranges which is either above or below that of either of the constituents alone.

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[3] Although the films studied here were not entirely stable, the main features of the variation of secondary emission with primary energy and with film thickness were verified by repeated trials on the same film and for films formed in several evaporation sequences.

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Corrections to H. Kayser's "Tabelle der Schwingungszahlen" [1]

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PROFESSOR H. KAYSER of Bonn, Germany has submitted the following table of corrections to his well-known and useful *Tabelle der Schwingungszahlen*. He states that these errors occurred on account of the bad state of his eyes. They have been found by himself and others, mostly by Dr. W. F. Meggers to whom he expresses his best thanks.

Because of the great usefulness of these tables to spectroscopists, and at the specific request of many readers of the *Physical Review*, these corrections to the tables are here presented.

EDITOR

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