AN EXPLANATION OF THE MAXIMUM IN SECONDARY ELECTRON EMISSION FROM METALS.

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When a beam of electrons of energy 'V' volts bombards a metallic target a fraction of its energy is used in heating the target and excite radiations while the rest appears in exciting secondary electrons. Considerable work has been done on the excitation of secondary electrons from metals. The general nature of the secondary electron emission curves is shown in Fig. 1. If 'I_s' denotes the total secondary electrons, 'I_p' the total primary electrons and 'V' the energy in volts of the bombarding electrons, the curve plotted for 'I_s/I_p' against 'V' increases with 'V' and attains a flat maximum at about a few hundred volts and slowly falls down for higher values of 'V'. (As a secondary structure the curve shows 'breaks' which correspond to the 'breaks' observed in the total intensity of the soft X-rays excited from the same metal.) The value of 'V' corresponding to the maximum is characteristic of the metal provided it is thoroughly degassed, and the purpose of the present paper is to give an explanation of the occurrence of this maximum in the secondary electron emission curves.

The exact nature of the mechanism of secondary electron emission is still obscure, though some of the experimental facts, especially those corresponding to lower values of 'V', have been to some extent explained. The existence of the maximum indicates that some process reverse to secondary electron emission must be going on within the metal target. The primary electrons penetrate deeper as their energy increases and consequently the corresponding secondary electrons are also generated deeper within the metal. The secondary electrons as a rule have small energies (of the order of a few volts only) and will be absorbed in trying to emerge out of the target. This at once explains the presence of the maximum in the above curve. The flat nature of the maximum can also be understood as the secondary electrons are generated not at one particular point but all along the path of the primary electrons in the metal.

This hypothesis can be verified roughly from the existing experimental data. According to Thomson–Whiddington Law the energy of a primary beam of electrons decreases according to the following relation:

\[ V_x^2 = V^2 - a.x. \]  

(1)
where \( V \) is the energy of the primary electrons, \( V_x \) is the energy after traversing a distance \( x \) in the metal and \( a \) is a constant depending on the metal of the target. The number of secondary electrons \( \delta I_s \) generated by the primary electrons of energy \( V \) in a distance \( \delta x \) within the target will be proportional to the number of primaries \( I_p \) and to the energy lost in the distance \( \delta x \). Thus,

\[
\delta I_s = K I_p \frac{\delta V}{\delta x} \delta x
\]  

(2)

Of these secondaries only a fraction will be able to come out of the target. If \( a \) is the coefficient of absorption, the number of secondary
electrons that will actually leave the target will be:

\[ \delta I_x = K_1 I_P \frac{\delta V}{\delta x} e^{-a \delta x} \]

\[ = K_1 I_P \frac{\delta V}{\delta x} \delta x (1 - a \delta x) \]  

(3)

Integrating equation (3) the total number of secondary electrons will be

\[ I_s = K_1 I_P \left( V - a \int_0^{x_{max}} \delta x \right) \]

(4)

The value of \( x_{max} \) is \( \frac{V^2}{a} \), from equation (1)

\[ \therefore \quad I_s = K_1 I_P \left( 1 - \frac{V^2}{a} \right) \]

\[ \therefore \quad I_s/I_P = K_1 V \left( 1 - \frac{a}{a} V^2 \right) \]

(5)

\[ 'a' \] is known to be of the order of \( 10^{11} \) and \( 'a' \) of the order of \( 10^5 \). Thus the second term in the right-hand side of equation (5) is negligible for small values of \( 'V' \) and the relation between \( 'I_s/I_P' \) and \( 'V' \) would be more or less linear as has been experimentally observed. The second term becomes of importance as \( 'V' \) increases and the curve should flatten for sufficiently high values of \( 'V' \). The maximum value of \( 'I_s/I_P' \) will correspond to the voltage obtained by differentiating and equating to zero the right hand side of equation (5). This value of \( 'V' \) is given by

\[ V_1 = \sqrt{\frac{K_1 a}{3a}} = k a \]

(6)

It is well known from the experiments of Whiddington and also of Terrill\(^8\) that \( 'a' \) varies as the density \( 'P' \) of the target. Thus the value of the energy of the primary electrons which corresponds to the flat maximum in the secondary electron curve should vary as the square-root of the density of the target. The accompanying figure shows the relation between \( '\rho_2' \) and the value of \( 'V' \) corresponding to the flat maximum taken from the existing data.\(^9\) It must be pointed out that the maximum is flat and as such the value of the corresponding voltage can be determined only approximately. As \( 'a' \) is of the order of \( 10^{11} \) and \( 'a' \) of the order of \( 10^5 \), this value of the voltage \( 'V_1' \) comes out to be of the order of 1000 from the last equation, which is of the order experimentally observed. Thus the general characteristics of the secondary electron emission can be satisfactorily explained by the assumption of absorption of the secondary electrons within the target.
Summary.

It is well known that the curve plotted for $I_s/I_p : V$, where $I_s$ is the total secondary electrons corresponding to the primary electrons $I_p$ of energy $V$ volts, shows a flat maximum at higher values of $V$. The presence of this maximum is explained on the assumption that the rate of loss of energy of the primary electrons obeys the Thomson–Whiddington Law and the secondary electrons generated at various depths are absorbed by the target on their way out. The relation derived on this assumption shows the dependence of the value of the voltage, corresponding to this maximum, on the density of the metal as has been observed experimentally.
REFERENCES.

   Copeland and Turnbull, *ibid.*, 1934, **45**, 463.