Correlation Between Variation of Secondary Electron Emission and Atomic Number

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The relative mean variation of the secondary emission as a function of the energy of the primary electrons is found to correlate with the atomic number of the elements bombarded. The evidence suggests that the secondary emission from a given element when bombarded by electrons of high energy may be represented to a first approximation by an equation of the form $R=k/E_p^s$, where R is the ratio of the total secondary current to the incident current and E_p is the energy of the incident beam. k and s are constants characterizing a given curve, and evidence is presented to show that s decreases as the atomic number increases. The significance of the correlation is very briefly discussed.

AS indicated by the work of Petry[1] the general form of the curve obtained when the magnitude of the secondary emission is plotted against the energy of the incident electrons is quite simple. For low primary energies (E_p) the ratio (R) of the return current to the incident current is quite low, but it increases rather rapidly as the primary energy is raised. It approaches a broad maximum at a primary energy of a few hundred volts, and then it decreases as the primary energy is raised still higher. The explanation suggested by Petry for this decline was the deeper penetration of the primaries of high energy.

In comparative studies of the secondary emission from different metals, the writer[2] observed a correlation to exist between the form of the secondary emission curves and the atomic number of the elements bombarded. This correlation was most apparent in the decrease of secondary emission with the increase of primary energy. The curves in which the decline was the most rapid were also the ones showing the highest secondary emission, and to eliminate the suspicion that the observed correlation was due entirely to this cause, the average slope ($\Delta R/\Delta E_p$) obtained from each graph in the region just above the maximum was divided by the magnitude (R) of the secondary emission. The earliest results showed that the relative mean slope ($M=\Delta R/R\Delta E_p$) correlated with atomic number, and that the relation was not far from linear.

Recently the work has been extended to include elements covering a larger range of atomic numbers. At the same time the range of the energies used has been considerably extended. Some of the results are shown in Fig. 1. For elements of low atomic number, the decline of the secondary emission just above the energy

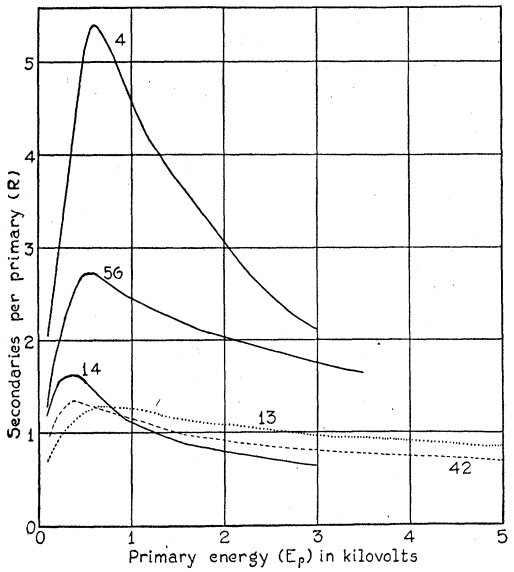

FIG. 1. Secondary electron emission as a function of primary energy. *Erratum:* The curve marked 13 is that obtained for tantalum, atomic number 73.

corresponding to the maximum is very rapid. At higher energies, however, the emission falls off less rapidly, and M is not constant throughout the range. The correlation between the variation of secondary emission and atomic number may be seen by plotting M, the relative mean slope in the first thousand volts above the maximum, against atomic number. Fig. 2 shows the results for sixteen elements examined by the writer.

[1] Petry, Phys. Rev. **26**, 358 (1922).
[2] Copeland, Thesis in the Department of Physics, State University of Iowa, July 1931.

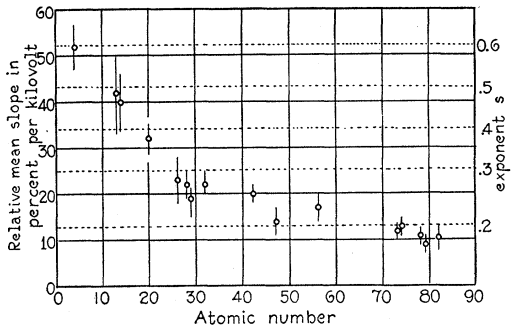

FIG. 2. Mean slope of secondary emission curves as a function of atomic number of target.

The lines indicate the range[3] of the determinations made from the various data. There appears to be a definite correlation between the slopes of the secondary emission curves and atomic number. The data could hardly be represented by a straight line, but the general trend of the observations included in Fig. 2 might be represented reasonably well by some inverse fractional power of atomic number.

Analysis of the data presented in Fig. 1 shows that the form of the curves at high energies might be represented to a first approximation by an equation of the form $R=kE_p^{-s}$ where both k and s vary from element to element. The correlation, noted above, may then be shown as a variation in the value of s required in this equation. This is accomplished by placing the values of s which correspond to chosen values of M at the right of Fig. 2. Thus, while at higher energies, each of the secondary emission curves may be represented as some inverse power of the primary energy, the power required decreases with atomic number. Even for the lightest of the elements examined, however, it is not as high as required by the theory of Frolich[4] who predicts that at high energies the emission should fall off as $E_p^{-\frac{3}{2}} \ln E_p^{\frac{1}{2}}/W_a$ where W_a is the inner potential of the metal.

These results may be taken as evidence that the decrease in secondary emission at high energies is connected with the deeper penetration of the primary electrons. In the results obtained by the writer, however, a rapid decline is generally preceded by a relatively rapid rise. One can make some progress toward an understanding of secondary emission as a function of primary energy on the basis of primary penetration and secondary diffusion with the sharing of energy. Electrons excited a certain depth, x, below the surface travel on the average a distance x^2 in diffusing back to the surface and probably excite other electrons which may contribute to the secondary current. It seems likely, then, that the secondary electrons resulting from energy lost at a certain depth would increase in number and decrease in energy as a function of the depth. Electrons coming from too great a depth would not have sufficient energy to escape. On this basis many of the observed phenomena may be understood.

[3] The quantity M is essentially a relatively small difference between two measured quantities, and the range of points as indicated by the lengths of the lines in Fig. 2 is not surprising. The consistency of the data seems good evidence for the existence of the correlation. In this connection, it may be well to point out that the writer has observed the first effect of surface contamination to be an alteration in the magnitude of the emission without observable alteration in the relative slopes of the graphs. Thus in the case of beryllium the writer analyzed curves for which the measured secondary emission differed by almost exactly a factor of two, yet the quantity M as computed from the two sets of data did not vary more than is indicated on the graph for atomic number 4. Such stability is evidence for the reliability of the correlation. Notice also that elements as dissimilar in general metallic properties as aluminum and silicon show excellent correlation.

[4] Frolich, Ann. d. Physik **13**, 229 (1932).