Absorption tables for electron probe microanalysis

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The values of the absorption correction \( f(X) \) are a function of the element from which the K, L, or M spectra is produced (1); the atomic number of the absorber, \( Z \) (2); the operating voltage, \( V_0 \) (3); the overvoltage \( V_0/V_r \) (4); and \( \lambda \), the absorption parameter (5). Three sets of tables have been prepared which, when used together, take into account these variables. These tables are calculated from the Philibert absorption correction and the Duncumb and Shields overvoltage correction.

Philibert [1] has developed an analytical expression for the absorption correction, namely:

\[
f(X) = \frac{(1+h)}{(1+\lambda/\sigma)} \left[ 1 + h(1+X/\sigma) \right]
\]

where \( \sigma \) is a modified Lenard coefficient, \( h = 1.2 \ A/Z^2 \), \( A \) and \( Z \) the mean atomic weight and atomic number, and \( X \) has its usual meaning in microanalysis. The expression above was fit to the experimental curves of Castaing [2] by adjusting the values of \( \sigma \) and \( h \). In this expression \( \sigma \) is dependent only on \( V_0 \), the operating voltage, and \( h \) only on \( A/Z^2 \).

The expression has proved useful for voltages well above the excitation potential \( V_r \), and for extrapolation between different values of \( Z \). Its accuracy is limited however to that of Castaing's curves. Green [3] has shown that the absorption parameter \( f(X) \) is strongly dependent on the difference between \( V_0 \) and \( V_r \). Thus, a correction to the Philibert equation becomes necessary.

Archard and Mulvey [4] have pointed out that the measured \( f(X) \) curve for \( \text{Al} \) reported by Castaing is in error. This is because Castaing used \( \text{Cu} \) as a tracer for \( \text{Al} \). The error in the \( \text{Al} \) curve follows from the fact that excitation potential for \( \text{Cu} \) (9 kV) is markedly different from that of the \( \text{Al} \) (1.6 kV). Therefore the measured curve of Castaing shows higher \( f(X) \) values throughout. This is also borne out by the measurements made by Green. Because the Philibert expression is fitted to the Castaing curves, it introduces substantial errors for low \( Z \) values.

The Philibert model has recently been modified by Duncumb and Shields * to account for the overvoltage effect. This modification accounts for the fact that the effective path length over which the characteristic radiation of an element is excited, is determined not only by the operating voltage but also by the excitation potential of the X-ray spectral series. This correction is made by calculating an effective Lenard coefficient, \( \sigma_{\text{eff}} \), from the following expression:

\[
\sigma_{\text{eff}} = 2.39 \times 10^5 / (V_0^{1.5} - V_r^{1.5})
\]

As before, \( V_0 \) is the applied voltage and \( V_r \) is the critical excitation potential for a particular element and spectral series. Both values are expressed in kV.

The overvoltage correction is illustrated in Fig. 1. $\sigma_{\text{eff}}$ and $V_{\text{eff}}$ are plotted versus the atomic number of the element being analyzed. The calculation was carried out for an operating voltage ($V_o$) of 30 kV for the K, L, and M spectra. For the K series where $V_o/V_r$ is less than 1.5, the effective operating voltage ($V_{\text{eff}}$) is less than 25 kV and a negative correction in $f(X)$ of over 15% must be made. Even though most electron probe work is done in the range where $V_o/V_r$ is greater than 2.0, the correction in $f(X)$ may be as high as 10%: the correction in $f(X)$ for the L and M series is much smaller than for the K series. However, even if the overvoltage correction in $f(X)$ is large, the overall effect on the absorption correction is much less since one uses ratios of $f(X)/F(X)$.

Because the values of $f(X)$ are a function of (1) the element from which the K, L, or M spectra is produced, (2) the average atomic number of the absorber, Z, (3) the overvoltage, $V_o/V_r$, (4) the operating voltage, $V_o$, and (5) the absorption parameter $\lambda$, we have prepared three sets of tables which, when used together, take into account these 5 variables. For alloys, a mean value of $Z$ is used [1], and $h$ is then obtained from Table 1.

Table 1* gives values of $h$ for the first 93 elements, where $h = 1.2 A/Z^2$. Table 2 gives the values of $\sigma_{\text{eff}}$ for all the elements at several operating voltages ($V_o$). The K, L, and M spectra are considered separately. Table 3 gives the values of $f(X)$ at selected intervals of $\sigma_{\text{eff}}$ for absorbers of different average atomic numbers. Values of $f(X)$ are listed over closely spaced intervals of $\lambda$ and extrapolation is usually not necessary.

Table 2* was calculated from Equation 2. The values of $V_o$ for the K, L, and M absorption edges were obtained from the X-ray Wavelength Tables of Bearden [5]. Table 3* was calculated from Equation 1 where $\sigma_{\text{eff}}$, was substituted for $\sigma$.

The following figures illustrate the usefulness of these tables. Both our calculations and those of Duncumb and Shields* were obtained from a combination of Equations 1 and 2. Fig. 2 shows $f(X)$ curves for Au L in Au, Cu K in Cu, and Cu K in Al at 29 kV. The curves of Castaing [2] are experimental and those of Duncumb and Shields* are calculated. The tabular values are also plotted. Fig. 3 shows our tabulated values, superimposed on the curves of Duncumb and Shields for Al K in Al and Cu K in Al at 29 kV and the values of Philibert [2] for pure Al. The experimental curves of Castaing [2] (Cu K in Al) and of Green [3] (Al K in Al) are also plotted. These curves illustrate the advantages of these tables, namely that one can determine not only $f(X)$ curves for pure elements, but also $f(X)$ curves for any type of
Fig. 2. Curves for Au L in Au, Cu K in Cu, and Cu K in Al at 2913

Fig. 3. Values for Al (Philibert) and the authors' tabulated values superimposed on the calculated curves of Duncan and Shields and the experimental curves of Castaing, and of Green for various materials.

Fig. 4. Variation of $f(x)$ with applied voltage
radiation in any matrix of interest. Fig. 4 illustrates the variation of \( f(X) \) with applied voltage. The agreement between calculated and measured values of \( f(X) \) is excellent. Excellent agreement between the tabular data and the experimental data of Green [2] is also found for \( C_K \) in Carbon at 10 kV.

The agreement between the calculated values of Duncumb and Shields* and the tabulated values from this study with experimental data is excellent. This agreement shows that the tables can be used with confidence for all the elements and for a range of operating potentials, from 5 to 35 kV. The tables and a section on how to use them, published as a NASA Technical Note, D-2984 can be obtained from the authors or from the Clearinghouse for Federal scientific and technical Information, Springfield, Virginia.

* For these tables, the reader is referred to NASA Technical Note D-2984.

REFERENCES