

4. PRODUCTION AND PROPERTIES OF RADIATIONS

0.5 for Z between 23 and 48. The ratio of $K\beta_3$ to $K\alpha_2$ rises fairly linearly with Z from 0.2 at $Z = 20$ to 0.4 at $Z = 80$ and that of $K\beta_1$ to $K\alpha_2$ is near zero at $Z = 29$ and rises linearly with Z to about 0.1 at $Z = 80$. Relative intensities of lines in the L spectrum are given by Goldberg (1961).

Green & Cosslett (1968) have made extensive measurements of the efficiency of the production of characteristic radiation for a number of targets and for a range of electron accelerating voltages. Their results can be expressed empirically in the form

$$N_K/4\pi = N_0/4\pi(E_0 - E_K - 1)^{1.63}, \quad (4.2.1.1)$$

where $N_K/4\pi$ is the generated number of $K\alpha$ photons per steradian per incident electron, N_0 is a function of the atomic number of the target, E_0 is the electron energy in keV and E_K is the excitation potential in keV. It should be noted that $N_K/4\pi$ decreases with increasing Z .

For a copper target, this expression becomes

$$N_K/4\pi = 1.8 \times 10^{-6} (E_0 - 8.9)^{1.63} \quad (4.2.1.2)$$

or

$$N'_K/4\pi = 1.1 \times 10^{10} (E_0 - 8.9)^{1.63}, \quad (4.2.1.3)$$

where $N'_K/4\pi$ is the number of $K\alpha$ photons per steradian per second per milliamper of tube current.

These expressions are probably accurate to within a factor of 2 up to values of E_0/E_K of about 10. Guo & Wu (1985) found a linear relationship for the emerging number of photons with electron energy in the range $2 < E_0/E_K < 5$.

To obtain the number of photons that emerge from the target, the above expressions have to be corrected for absorption of the generated radiation in the target. The number of photons emerging at an angle φ to the surface, for normal electron incidence, is usually written

$$N_\varphi/4\pi = f(\chi)N/4\pi, \quad (4.2.1.4)$$

where $\chi = (\mu/\rho) \text{ cosec } \varphi$ (Castaing & Descamps, 1955). Green (1963) gives experimental values of the correction factor $f(\chi)$ for a series of targets over a range of electron energies. His curves for a copper target are given in Fig. 4.2.1.1. It will be noticed that the correction factor increases with increasing electron energy since the effective depth of X-ray generation increases with voltage. As a result, curves of N_φ as a function of E_0 have a broad maximum that is displaced towards lower voltages as φ decreases, as shown in the experimental curves for copper K radiation due to Metchnik & Tomlin (1963) (Fig. 4.2.1.2). For very small take-off angles, therefore, X-ray tubes should be operated at lower than customary voltages. Note that the values in Fig. 4.2.1.2 agree to within $\sim 40\%$ with those of Green & Cosslett. $f(\chi)$ at constant E_0/E_K increases with increasing Z , thus partly compensating for the decrease in N_K , especially at small values of φ . A recent re-examination of the characteristic X-ray flux from Cr, Cu, Mo, Ag and W targets has been carried out by Honkimaki, Sleight & Suortti (1990).

4.2.1.2. The continuous spectrum

The shape of the continuous spectrum from a thick target is very simple: I_ν , the energy per unit frequency band in the spectrum, is given by the expression derived by Kramers (1923):

$$I_\nu = AZ(\nu_0 - \nu) + BZ^2, \quad (4.2.1.5)$$

where Z is the atomic number of the target and A and B are constants independent of the applied voltage E_0 . B/A is of the order of 0.0025 so that the term in Z^2 can usually be neglected (Fig. 4.2.1.3). ν_0 is the maximum frequency in the spectrum, *i.e.* the Duane–Hunt limit at which the entire energy of the bombarding electrons is converted into the quantum energy of the emitted photon, where

$$h\nu_0 = hc/\lambda_0 = E_0. \quad (4.2.1.6)$$

Using the latest adjusted values of the fundamental constants (Cohen & Taylor, 1987):

$$\begin{aligned} hc &= 1.23984244 \pm 0.00000037 \times 10^{-6} \text{ eV m} \\ &= 12.3984244 \pm 0.0000037 \text{ keV } \text{\AA}. \end{aligned}$$

Equation (4.2.1.5) can be rewritten in a number of forms. If dN_E is the number of photons of energy E per incident electron,

$$dN_E = bZ(E_0/E - 1) dE, \quad (4.2.1.7)$$

where $b \sim 2 \times 10^{-9}$ photons eV⁻¹ electron⁻¹, and is known as Kramer's constant.

From (4.2.1.7), it follows that the total energy in the continuous spectrum per electron is

$$\int_0^{E_0} E dN_E = bZE_0^2/2. \quad (4.2.1.8)$$

Since the energy of the bombarding electron is E_0 , the efficiency of production of the continuous radiation is

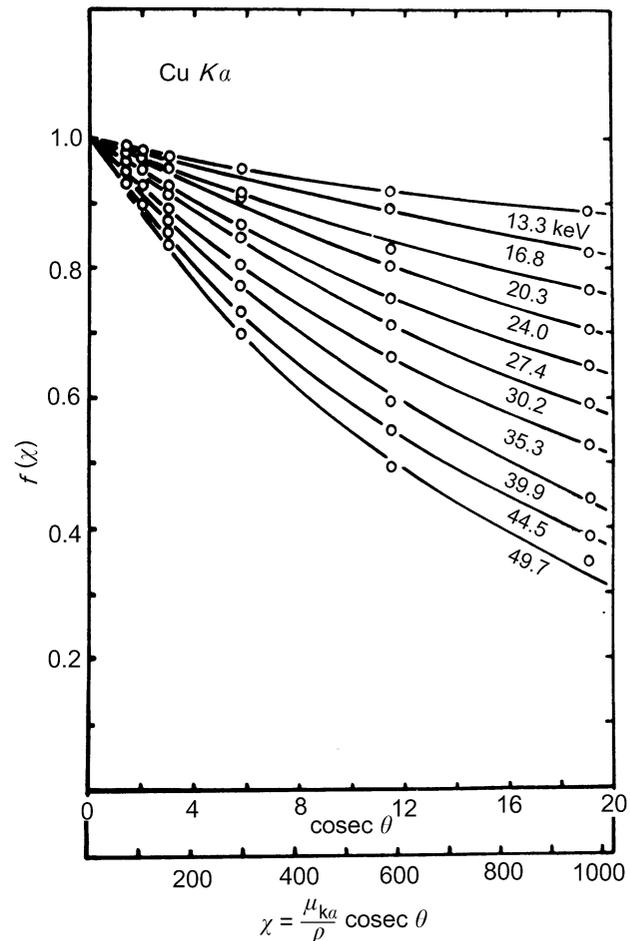


Fig. 4.2.1.1. $f(\chi)$ curves for Cu $K-L_3$ at a series of different accelerating voltages (in kV). From Green (1963).