51 l

ABSOLUTE INTENSITIES OF CHARACTERISTIC Kα RADIATION FROM AN INCLINED COPPER TARGET

By V. METCHNIK*

[*Manuscript received July* 17, 1963]

Summary

Experimental results are given for the measurements of the absolute intensity of characteristic Kα radiation from a thick copper target when the normal to the target is inclined to the incident electron beam at an angle θ equal to 20°, 30°, 40°, and 50°. These measurements cover a range of electron energies between 20 and 50 kV, and take-off angles ϕ ranging from 1° to 50°. A comparison is made with the emission at normal incidence. The copper Kα radiation was isolated by means of balanced nickel and iron filters, and the intensity measurements were made with a scintillation counter with NaI(Tl) crystal.

I. INTRODUCTION

A theoretical discussion on the absolute intensities of characteristic Kα emission, together with the experimental results for normal incidence of the electron beam on targets of copper, silver, and chromium has already been given (Metchnik and Tomlin 1963).

It can readily be shown that, when the normal to the target is inclined at an angle θ to the incident electron beam (Fig. 1), the equation governing the emission is given by

$$N_\phi = k\int_{T_0}^{T_\mathrm{k}} NQ\frac{\mathrm{d}s}{\mathrm{d}T}\exp(-\mu\langle x\rangle\cos\theta\,\mathrm{cosec}\,\phi)\mathrm{d}T, \tag{1}$$

where $N_\phi/4\pi$ is the number of quanta emitted per unit solid angle in the direction ϕ for each incident electron, T_k is the K ionization energy of the target atoms, T_0 is the incident electron energy, N is the number of atoms per unit volume in the target, Q is the total cross section for K-shell ionization, S is the total path length of the electrons in the metal target, μ is the linear absorption coefficient of the Kα radiation in the target material, and $\langle x\rangle$ is the "average distance" below the target surface for electrons with a path length equal to S. The factor k (Worthington and Tomlin 1956) embodies the following corrections: (*a*) electron rediffusion, (*b*) ratio of Kα to Kβ radiation, (*c*) fluorescence yield, (*d*) production of Kα quanta by the white radiation.

The expression for N_ϕ predicts that the intensity of the characteristic Kα radiation should increase the greater the angle θ that the normal to the target makes with the incident electron beam. However, the exponential factor in the integrand of equation (1), i.e. $\exp(-\mu\langle x\rangle\cos\theta\,\mathrm{cosec}\,\phi)$, shows a small variation for values of θ within the range $0° \leqslant \theta \leqslant 10°$. Experimentally, the increase in the value of the exponential term and hence in the emission should be easily detectable for values of $\theta \geqslant 20°$.

* Physics Department, University of Adelaide.

The values of N_ϕ obtained for varying values of ϕ and θ, and for accelerating voltages ranging from 20 to 50 kV for the incident electron beam are presented in tabular form. There are no data available with which the present measurements on emission from inclined targets may be compared.

II. Experimental

The apparatus used for these measurements has already been described elsewhere (Metchnik and Tomlin 1963). The X-ray detecting apparatus (consisting of a defining aperture followed by balanced nickel and iron filters, and a scintillation counter) was attached to an arm pivoted on the axis of the target chamber. The

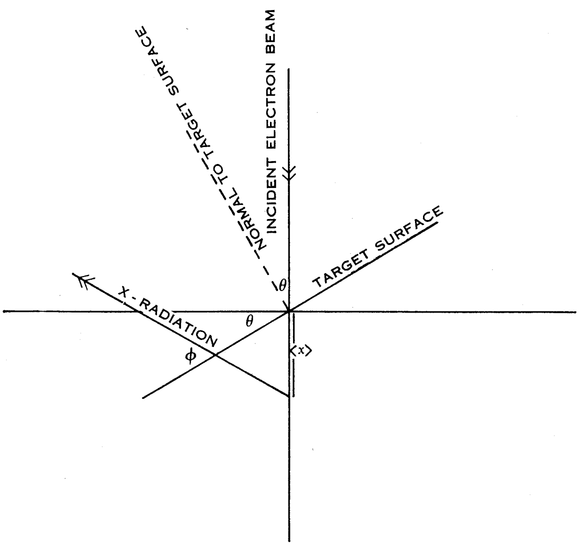

Fig. 1

electron beam current (of the order of 10^{-7} A), and the defining aperture, which subtended a solid angle of $0 \cdot 24 \times 10^{-4}$ steradians, at the target ensured that the counting rate (about 1000 counts per second) was sufficiently low to avoid any error caused by counting losses. The target was rotated through a fixed angle θ with respect to the incident electron beam, the scintillation counter positioned at various take-off angles ϕ, and the counting rate recorded.

III. Results and Discussion

The results of these measurements after correcting for absorption of radiation by windows, foils, and air path between the target and the scintillation counter are shown in Tables 1–4. Figure 2 shows the values of the absolute intensity of emission at 30 kV as a function of take-off angle ϕ, for values of θ equal to 30° and 50°, and these values are compared with the values of emission at normal incidence, i.e. for $\theta = 0°$.

From equation (1), it would be expected that the larger the value of θ, the larger would be the intensity of emission for a fixed take-off angle ϕ and a fixed accelerating voltage. since in effect, the rotation of the target, as shown in Figure 1,

TABLE 1

ACCELERATING VOLTAGE 20 kV: VALUES OF $N_{\phi} \times 10^4$

ϕ \ θ	0	20	30	40	50
1	3·6	3·7	3·8	3·9	4·1
3	7·4	7·4	7·6	7·8	8·0
5	9·2	9·3	9·7	9·6	9·5
10	10·1	10·2	10·5	10·8	10·9
20	10·6	10·7	10·8	11·5	11·5
30	11·0	11·0	11·4	11·5	11·5
40	11·2	11·2	11·4	11·5	11·5
50	11·4	11·2	11·4	11·5	11·5

TABLE 2

ACCELERATING VOLTAGE 30 kV: VALUES OF $N_{\phi} \times 10^4$

ϕ \ θ	0	20	30	40	50
1	6·0	6·3	6·5	6·4	6·4
3	11·2	13·6	15·4	15·9	16·1
5	15·0	16·3	18·2	19·2	19·2
10	20·0	21·1	22·7	23·4	23·7
20	26·0	28·3	29·1	30·4	30·5
30	27·2	29·4	30·8	31·9	32·2
40	28·0	29·6	31·0	32·8	33·2
50	28·0	29·6	31·0	33·0	33·2

TABLE 3

ACCELERATING VOLTAGE 40 kV: VALUES OF $N_{\phi} \times 10^4$

ϕ \ θ	0	20	30	40	50
1	5·47	6·4	5·6	5·7	5·7
3	18·0	19·2	20·0	20·8	20·9
5	21·7	23·8	24·2	25·1	25·3
10	30·0	32·0	32·6	33·4	33·4
20	38·8	39·0	39·8	40·7	40·6
30	44·5	44·7	44·6	44·9	44·7
40	45·1	45·1	45·1	45·2	45·2
50	45·1	45·2	45·3	45·2	45·2

corresponds to a shorter path length that the X-ray quanta have to traverse before emerging at the target surface and hence would suffer less absorption. The experimental results show, however, that the increases in emission from inclined targets differ with varying take-off angles ϕ from the values obtained from the evaluation of the integral in equation (1). At higher voltages and small take-off angles the

TABLE 4

ACCELERATING VOLTAGE 50 kV: VALUES OF $N_\phi \times 10^4$

ϕ \ θ	0	20	30	40	50
1	5·0	6·8	5·1	5·2	5·2
3	17·7	20·4	20·8	21·1	21·2
5	26·0	28·2	29·2	30·6	30·5
10	39·8	42·0	42·7	43·4	43·5
20	51·1	51·6	51·8	51·8	52·0
30	60·4	61·3	61·9	62·1	61·5
40	61·9	62·2	62·0	62·3	62·1
50	62·0	62·2	62·0	62·4	62·4

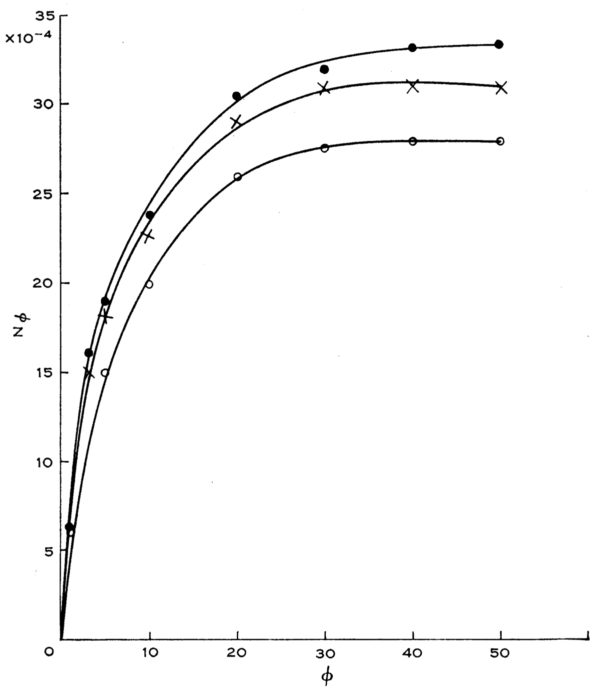

Fig. 2.—Comparison of emission for inclined and normal incidence at 30 kV. $N_\phi/4\pi$ is the number of quanta emitted per unit solid angle in the direction ϕ for each incident electron. The symbols used are as follows: ○, $\theta = 0°$; ×, $\theta = 30°$; ●, $\theta = 50°$.

theoretical values of emission are larger than the experimental values, while for large take-off angles and for the range of accelerating voltages considered the opposite is true. The maximum discrepancy between theory and experiment, however, is not more than 25%.

A measure of reconciliation can be achieved by considering the factor k occurring in equation (1). Only the electron rediffusion (which for thick targets has the effect of diminishing the intensity of X-rays emitted due to the backscattering of fast electrons) embodied in this factor would be expected to alter when the normal to the target is inclined to the incident electron beam. Palluel (1947) and more recently Holliday and Sternglass (1957) have measured the number of backscattered electrons from metal targets. Unfortunately, their results refer only to normal incidence of the primary electron beam on the target surface, with a maximum of 20 kV for the energy of the primary beam. No data appear to be available in the literature on backscattering at higher voltages and from inclined metal targets. However, preliminary measurements carried out by the author indicate that, for a fixed value of the incident electron beam, the fast backscattered electrons increase with increasing angle of rotation of the target. This would certainly have the effect of decreasing the calculated values of emission as given by equation (1).

IV. Acknowledgment

The author would like to thank Dr. S. G. Tomlin for his help and guidance throughout this project.

V. References

Holliday, J. E., and Sternglass, E. J. (1957).—*Brit. J. Appl. Phys.* **28**: 1189.
Metchnik, V., and Tomlin, S. G. (1963).—*Proc. Phys. Soc. Lond.* **81**: 956.
Palluel, P. (1947).—*C. R. Acad. Sci., Paris* **224**: 1492.
Worthington, C. R., and Tomlin, S. G. (1956).—*Proc. Phys. Soc. Lond.* **69**: 401.