REMARKS ON THE EFFICIENCIES OF GEIGER, PROPORTIONAL, AND SCINTILLATION COUNTERS WITH APPLICATION TO THE ABSOLUTE INTENSITY OF CHARACTERISTIC X-RADIATION

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Summary

The measurements of the absolute intensities of Cu Kα radiation, isolated by means of balanced nickel and iron filters, necessitated the determination of the quantum counting efficiency of three types of detectors: an end-window argon-filled Geiger counter, a two side-window, xenon-filled proportional counter, and a scintillation counter with NaITl crystal. It is shown that, provided the necessary corrections are made, results of absolute intensity measurements obtained with these three detectors show good agreement.

I. INTRODUCTION

One of the main requirements demanded of a detector is that it have a high quantum counting efficiency. Assuming that every absorbed quantum is "counted", then the quantum counting efficiency is defined as "the percentage of incident monochromatic X-ray quanta that produce detectable electrical impulses" (Parrish and Kohler 1956). It is calculated as the product of the gas or the scintillation crystal absorption and the detector window transmission.

Gas counters like the Geiger and proportional counters are either of the end-window type or the side-window type. However, if the efficiency of the end-window type counters were calculated from the absorption in the gas of the counter using published values of the absorption coefficients, an incorrect result would be obtained. This is because in end-window counters not only is the field not uniform along the length of the anode wire, but the window and high tension side of the counter are at a small distance from the ends of the anode wire, with a result that there is a "dead volume" of gas near the ends. The errors due to dead volume may be offset in counters having a side window, since the absorption of X-radiation now takes place in a region of uniform field distribution and the quantum counting efficiency as a function of gas absorption can now be calculated. However, because of the shorter path length of the radiation in side-window counters, not only must a heavier gas such as xenon be used (rather than argon or krypton, as in end-window counters) but a second window must be placed opposite the entrance window to avoid fluorescence from the counter tube walls.

A scintillation counter with NaITl crystal, since the latter is hygroscopic, is hermetically sealed in an aluminium holder, and the quantum counting efficiency is given by the product of the crystal absorption and transmission through the holder.

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The measurements on absolute intensity of copper Kα radiation, using a Geiger, a proportional, and a scintillation counter, were observed for take-off angles ϕ in the range 1°–50°, and for accelerating voltages of the X-ray tube in the range 20–40 kV. Results obtained using these three detectors show less than 10% variation.

II. Correction for the Dead Volume of the End-window Geiger Counter

Consider X-radiation falling on an end-window Geiger counter of length L. If for the moment one neglects the absorption in the window of the counter and if μ is the linear absorption coefficient of the counter gas for a particular wavelength, then if the counter is considered to be an ideal one, that is, the absorption of X-radiation is uniform along its length and every quantum absorbed gives rise to a "count", a plot of counting rate against counter length would give rise to a line of zero slope.

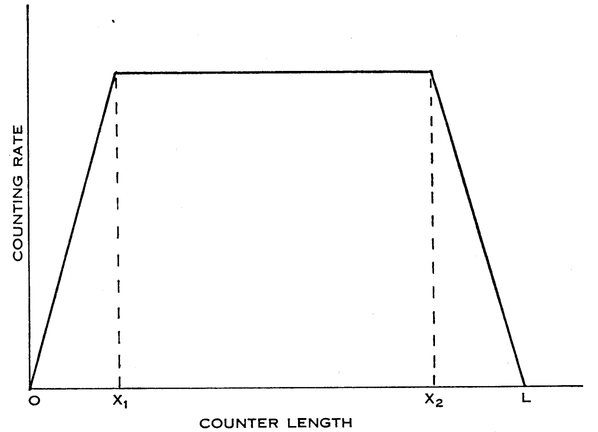

Fig. 1.—Assumed plot of counting rate against counter length for an end-window counter.

In travelling a distance x in the counter gas, the number of quanta (of wavelength λ) absorbed is proportional to

$$1-\exp(-\mu x),$$

while in travelling a distance $x+\Delta x$, the absorption is proportional to

$$1-\exp[-\mu(x+\Delta x)].$$

Hence the number absorbed in a small distance Δx is proportional to

$$\mu \exp(-\mu x)\Delta x+ \ . \ . \ . \text{ higher order terms.}$$

If the counter does not record uniformly along its length L, i.e. if the plot of counting rate against counter length is assumed to be as shown in Figure 1, then the probability that quanta be counted before X_1 will be proportional to

$$\int_0^{X_1} \rho(x)\, \mu \exp(-\mu x)\mathrm{d}x, \text{ where } \rho(x) = \frac{x}{X_1} \text{ for } 0 < x < X_1.$$

Thus for a counter of length L, we may write,

$$\frac{\text{Number of quanta that would be recorded in ideal case}}{\text{Number of quanta actually recorded}}$$

$$= \frac{\int_0^L \mu \exp(-\mu x)\mathrm{d}x}{\int_0^L \rho(x)\ \mu \exp(-\mu x)\mathrm{d}x}, \qquad \rho(x) = \begin{cases} \dfrac{x}{X_1}, & \text{for } 0 \leqslant x \leqslant X_1, \\ \dfrac{L-x}{L-X_2}, & \text{for } X_2 \leqslant x \leqslant L. \end{cases}$$

III. Measurements of the Sensitivity of an End-window Geiger Counter

Following the method of Arndt (1953), a collimated beam of γ-rays from a ^{60}Co source placed at a distance of 3 ft from the counter was used, the beam being incident at right angles to the axis of the Geiger counter. In front of the counter was a lead shield screen $\frac{1}{4}$ in. thick with a slit 1 cm long and 1 mm wide, enabling the whole of the central wire of the counter to be irradiated. Starting with the counter window parallel to the slit, the Geiger counter was moved equal distances of $0 \cdot 5$ cm parallel to its axis and the rate of counting recorded. A plot of counting rate against counter length is shown in Figure 2.

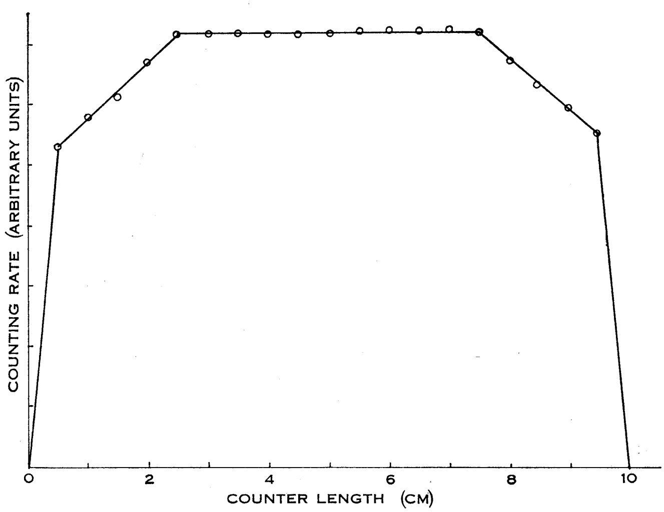

Fig. 2.—Experimental result of counting rate against counter length for an end-window, argon-filled Geiger counter, 10 cm long.

From this result it is calculated that in measurements of absolute intensity of Kα emission using a Geiger counter, the value for the quantum counting efficiency as calculated from absorption data must be increased by 14% to account for sensitivity losses.

IV. Experimental Method and Results

The apparatus and method used in the determination of the absolute intensity of emission has already been described (Metchnik and Tomlin 1963). The copper Kα radiation was isolated by means of balanced nickel and iron filters. The beam current (of the order of 10^{-7} A) and the defining aperture (which subtended an angle of $0 \cdot 24 \times 10^{-4}$ steradians at the target) ensured that the counting rate was sufficiently low to avoid any error caused by counting losses when using the proportional and the scintillation counters. A probe unit with a known quenching time of 300 μs was used in conjunction with the Geiger counter for all measurements involving the latter, thus allowing corrections for counting losses to be made.

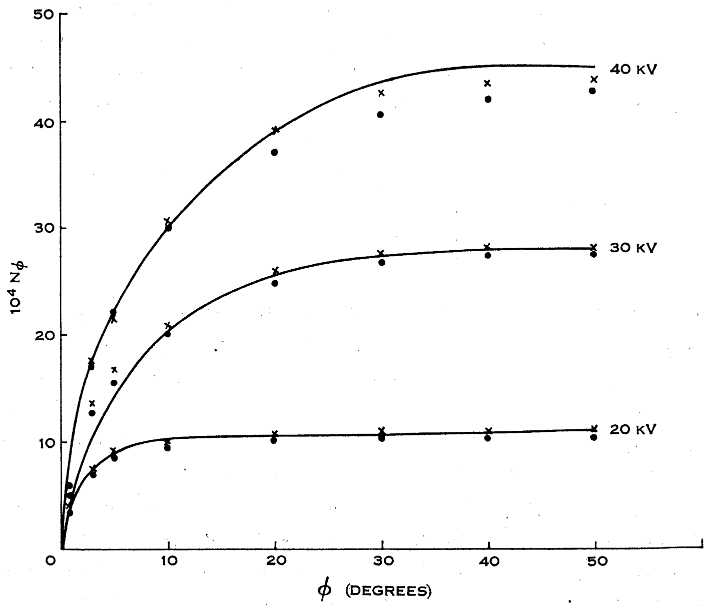

Fig. 3.—Experimental results for copper Kα emission at 20, 30, and 40 kV energy of the electron beam, as a function of take-off angle ϕ, using a Geiger, a proportional, and a scintillation counter with NaITl crystal. $N_\phi/4\pi$ is the number of quanta emitted per unit solid angle in the direction ϕ for each incident electron. ———— Scintillation counter. ● Geiger counter. × Proportional counter.

The end-window Geiger counter used contained argon at a pressure of 60 cmHg with an overall length of 10 cm and had a mica-beryllium window with a transmission of 97·3%.

The two side-window proportional counter contained xenon gas at a pressure of 70 cmHg and had a diameter of 1·9 cm. Each mica-beryllium window had a transmission of 88·4%.

The scintillation counter comprised a NaITl crystal 1 mm thick and an 11- stage photomultiplier tube. The NaITl crystal was hermetically sealed in an aluminium holder that allowed 71·0% transmission.

The absorption coefficient for the NaITl crystal was calculated from the equation (Klugg and Alexander 1954)

$$\left(\frac{\mu}{\rho}\right)_{\mathrm{NaI}} = \frac{1}{W_{\mathrm{NaI}}} \sum_i W_i \left(\frac{\mu}{\rho}\right)_i$$

$$= \frac{1}{W_{\mathrm{NaI}}} \left\{ W_{\mathrm{Na}} \left(\frac{\mu}{\rho}\right)_{\mathrm{Na}} + W_{\mathrm{I}} \left(\frac{\mu}{\rho}\right)_{\mathrm{I}} \right\},$$

where W_{NaI} is the molecular weight of sodium iodide, and W_{Na} and W_{I} are the atomic weights of sodium and iodine respectively, and $(\mu/\rho)_{\mathrm{Na}}$ and $(\mu/\rho)_{\mathrm{I}}$ are the mass absorption coefficients of sodium and iodine respectively for copper Kα radiation.

Results of the intensities of copper Kα emission obtained with the three detectors after correcting for quantum counting efficiencies of the counters and for absorption of radiation by X-ray tube window, foils, and air path between target and detectors are shown in Figure 3 for accelerating voltages of the primary electron beam of 20, 30, and 40 kV as a function of take-off angle ϕ.

These curves show that there is less than 10% variation between the intensity values obtained with the three detectors.

V. Conclusion

The results indicate the possibility of extending these measurements to targets such as aluminium (At. No.: $Z = 13$) and carbon (At. No.: $Z = 6$). Even for the case of an aluminium target however, because of the long wavelength of the aluminium Kα line (8 Å), there is a very large decrease in the quantum counting efficiency of a scintillation counter due to the increased absorption in the aluminium holder containing the NaITl crystal. Furthermore, owing to the short path length in a two side-window counter (together with the absorption in the two windows), the quantum counting efficiencies would again be greatly reduced. Since the most accurate intensity measurements are obtained in the least time with the highest intensity, it seems reasonable therefore to expect that measurements of absolute intensities on elements of low atomic numbers will be made with end-window counters, preferably of the flow type, and this would certainly entail a determination of counter sensitivity with length.

VI. Acknowledgment

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VII. References

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