# EFFECT OF WINDOW ABSORPTION AND SOURCE BACKING ON β-SPECTRA

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## Introduction

The distortive effects due to absorption and scattering of electrons in the counter window, in source backing and in the material of the source itself were noted quite early in the development of β-ray spectroscopy. It was by recognising these effects that the β-disintegration theory of Fermi was experimentally established by Lawson and Cork (1940), and Tyler (1939). With these facts in mind, very thin sources and source backings and also counter windows are employed in such work. These precautions only minimise the distortive effects, so that the true electron spectrum is obtained only if the correction factors for each of these sources of distortion are known. The part played by such and other effects in the study of shapes of β-spectra was discussed by Thosar (1958) and a survey of the earlier work was presented by Slätis (1958). The present work deals with an estimation of these correction factors and their application to the β-spectrum of $Pm^{147}$.

### (*A*) *Window Absorption*

The effect of counter window absorption was studied in the intermediate image β-ray spectrometer using a thin source of $Tl^{204}$ deposited on an aluminium backing (0·160 mgm./cm.$^2$) and using collodion films 0·060 to 0·960 mgm./cm.$^2$ thick as counter windows. From the observed β-spectra, correction factors for window absorption were obtained in the conventional way. These could be represented by the formula,

$$f_W = e^{\mu x} \tag{1}$$

with

$$\mu = 1306\,(E - E_c)^{-2.1} \tag{2}$$

where electron energy E is in Kev. $E_c$ is given in equation (3), and the mean surface density of the window ($x$) in mgm./cm.$^2$ Due to uncertainties in the determination of low electron energy and intensity due to remanance effects

of the spectrometer and uncertainties in the thickness due to local density fluctuations, errors in these correction factors are estimated to be about 5% for electron energies above 10 Kev., and much larger for lower energies.

Corresponding to a window thickness $x$ mgm./cm.$^2$ there exists a minimum energy of electrons $E_c$ Kev. at which transmission of electrons just starts. This is termed the cut-off energy. It is found that

$$x = 0{\cdot}007\, E_c^{1{\cdot}625}. \tag{3}$$

These determinations are in good agreement with those on low energy electrons ($< 200$ Kev.) by Schönland (1925) and others (Slätis, 1955).

The mean angle ($\theta$) of incidence of the electron beam was, in the present case, about 45°. Neglecting the small contribution from large angle scattering in collodion (considered for the present treatment as essentially Carbon and Hydrogen) to these correction factors, one can generalize the above formulæ (1) and (3) so as to be applicable for any spectrometer geometry with a mean angle of incidence, $\theta$, of the electron beam in the form

$$f_W = \text{exp. } [900\,(E - E_c)^{-2{\cdot}1}\, x\, (\cos\theta)^{-1}] \tag{4}$$

and

$$x = 0{\cdot}01\, E_c^{1{\cdot}625} \cos\theta \tag{5}$$

These relations are applicable for $E < 200$ Kev. and $x < 1$ mgm./cm.$^2$

(*B*) *Backscattering*

Though many workers have observed the effect of backscattering, correction factors to the electron spectrum have not been quantitatively determined except for integral β-spectra with very different maximum energies and orders of forbiddenness. On the theoretical side, the multiplicity and variety of processes that contribute to backscattering has made it very difficult to obtain accurate expressions by means of which corrections for such effects may be derived.

In this work, the effect of backscattering was studied using a thin source of $Tl^{204}$, a counter window 0·1 mgm./cm.$^2$ thick and aluminium source backings from 0·2 to 2 mgm./cm.$^2$ thick. Defining the ratio of the number of electrons observed with backscattering to those without backscattering as the backscattering factor, the relationship between backscattering factor $p$, and backing thickness for various electron energies are presented in Fig. 1. From these curves correction factor $f_b$ for backscattering at any backing thickness and any electron energy in the range of 20 to

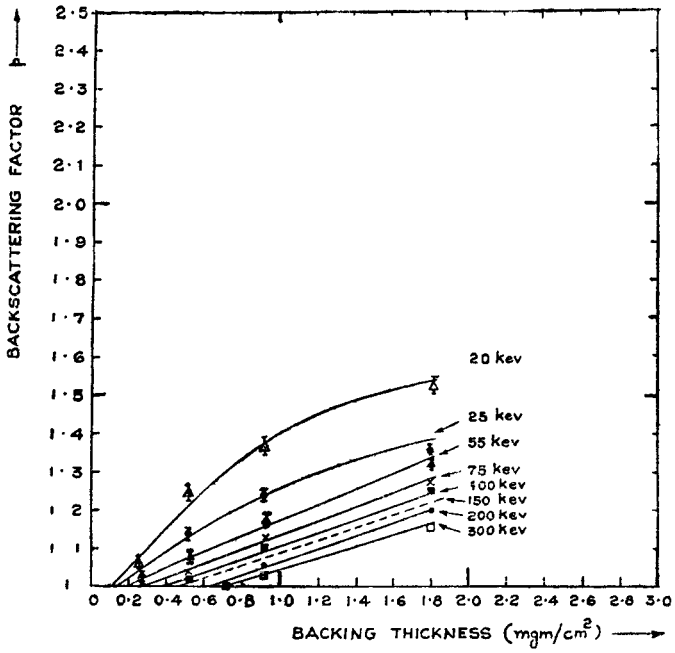


FIG. 1. Backscattering of low energy electrons in thin aluminium.

300 Kev. may be obtained as reciprocals of $p$. The observations below 20 Kev. are much affected in accuracy due to uncertainties in the determination of low electron energy and electron intensity as pointed out in Section A and due to errors in determining the intensity of electrons at zero backing thickness.

Bothe (1933) has discussed the experimental observations on backscattering, or more precisely, backdiffusion. Accordingly, backscattering should increase with increasing thickness of the scatterer until after a certain thickness, which depends on electron energy and the scattering material, it reaches a saturation value. This saturation backscattering factor is itself found to be little energy dependent but strongly dependent on the coulomb field of the scattering nucleus. In the present case, 1·8 mgm./cm.$^2$ does not appear to provide saturation backscattering thickness for electron energy greater than 25 Kev. The new feature observed in these curves (Fig. 1) is the intercept on the axis of backing thickness. This implies that backscattering is initiated, as it were, at a minimum backing thickness. Denoting this scatter-initiating thickness by $t_0$ (mgm./cm.$^2$), it was found that

$$t_0 = 0{\cdot}0110\, E^{0,755} \qquad (E \leqslant 300 \text{ Kev.}) \qquad (6)$$

This expression should be quite useful in estimating the backing thickness which may be employed without appreciable backscattering contribution for electrons of energy above E Kev. The error in $t_0$ is estimated to be about 10% for electron energy greater than 20 Kev.

Experimental evidence (Bothe, 1933) indicates that backscattering, particularly before backdiffusion stage is reached, is essentially due to large angle coulomb scattering of incident electrons by nuclei. So, the cross-section for such a process, in ideal single scattering approximation, is given by the well-known Rutherford's formula,

$$\frac{d\sigma}{d\Omega} = \frac{Z^2 e^4}{16 E^2} \frac{1}{\sin^4 \frac{\theta}{2}}. \tag{7}$$

It follows that for a given energy and large angle scattering, the cross-section for backscattering is relatively much larger in heavier elements than in lighter ones. For light elements, like aluminium under consideration, due to the low cross-section for large angle scattering, electrons of this range should traverse a finite thickness of the scattering material before having a good chance of being backscattered. This is what has been observed in this work and called the scatter-initiating thickness. It may now be seen that this thickness should vary inversely as the cross-section for large angle scattering. In materials like gold and lead, the probable thickness that low energy ($< 300$ Kev.) electrons traverse before being backscattered should be of the order of a few atomic layers. When comparatively thick scatterers and electrons of a continuous range of energy are involved, this scatter-initiating thickness is obscured. This is what appears to have happened in earlier works.

It may be noted that the geometry of acceptance in this β-ray spectrometer and the interscattering between the layer of source material and source backing play a very important role in the backscattered electron distribution, referred to here. These results on backscattering are applicable to the geometry found in the intermediate image β-ray spectrometer.

### (C) *Application to the β-Spectrum of* $Pm^{147}$

Correction factors determined in the way described above have been applied to the non-unique first forbidden β-spectrum of $Pm^{147}$, which was shown by Langer (1950) and Maize and Zaffrano (1953) to have a straight line Kurie plot down to about 10 Kev.

A thin source of $Pm^{147}$ deposited by evaporation on to an aluminium backing (·750 mgm./cm.$^2$) was used to observe the β-spectrum. The Geiger

counter window of collodion was 0·080 mgm./cm.$^2$ thick. In view of nearly 6% uncertainty in backscattering correction factors, observed points at electron energies greater than 100 Kev. where these correction factors are $\geq 0{\cdot}95$, are not corrected.

The Kurie plot as observed (curve A), after being corrected for absorption in the counter window using correction factors discussed above (curve B), and after correcting for backscattering effects also (curve C), using the data presented in Fig. 1, are shown in Fig. 2.

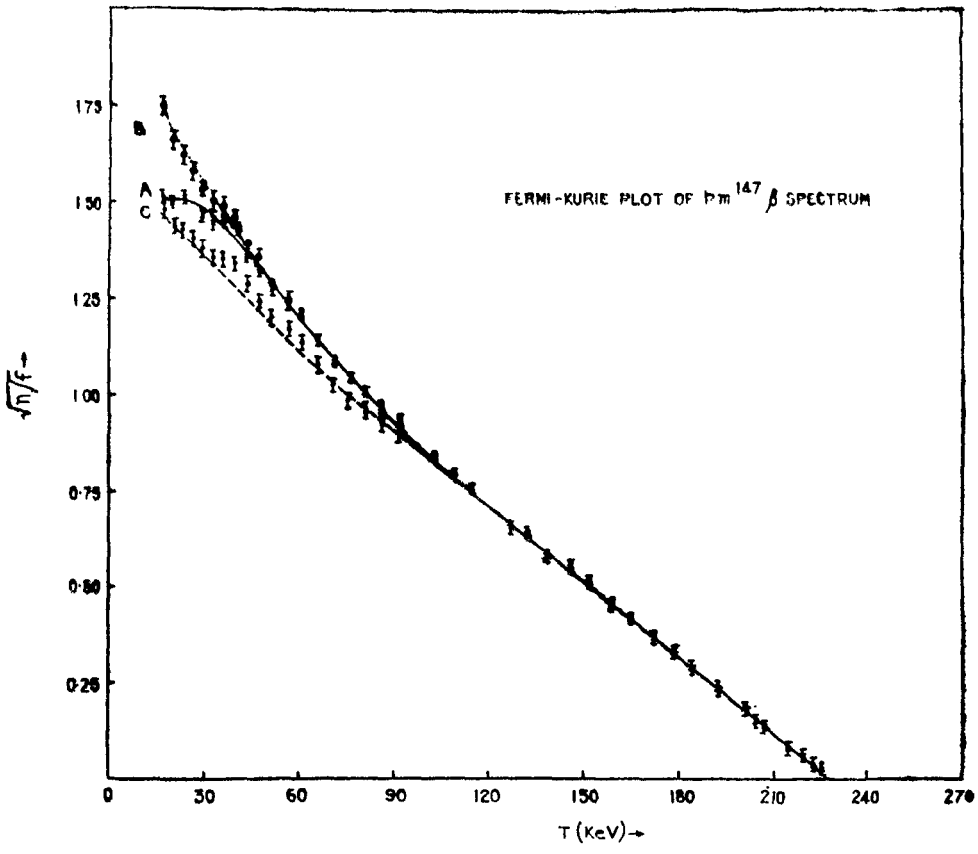


Fig. 2. Kurie plots of $Pm^{147}$ $\beta$-spectrum; A, uncorrected; B, corrected for window absorption; C, corrected for backscattering also.

The slight departure from linearity of the final curve (Fig. 2) is attributed at least in part to the finite thickness of the source and consequent self-absorption and self-scattering.

*Note added in Proof:*

Recently Gubernator and Flammersfeld (*Zeit. Phys.*, 1959, 156, 179) have found a formula for absorption of low energy electrons in various materials. In the notation of the present work, it may be written as $E_c = 14 \cdot 3 (Z^{4/3}/A)\ x^{0 \cdot 61}$. Considering the probable formula, $C_6H_8O_9N_2$ for collodion, equation (5) can be rewritten as $E_c = 15\ (Z^{4/3}/A)\ x^{0 \cdot 615}$ Due to lack of knowledge of the accurate formula for collodion, the two observations should be considered to be in agreement.


## SUMMARY

Estimates of the distortive effects of window absorption and backscattering from source backings on β-spectra are presented as observed in the intermediate image β-ray spectrometer. The existence of a scatter-initiating thickness is pointed out and explained. These correction factors are applied to the β-spectrum of $Pm^{147}$ to estimate their validity.



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