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Contract No. W-7405-Eng. -48

THE RELATION OF BACKSCATTERING TO SELF-ABSORPTION

By

Peter E. Yankwich and John Weigl

Special Review of Declassified Reports

Authorized by USDOE JK Bratton

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Berkeley, California

THE RELATION OF BACKSCATTERING TO SELF-ABSORPTION

By

Peter E. Yankwich and John Weigl

Department of Chemistry
and Radiation Laboratory,
University of California, Berkeley.*

12 January 1948

ABSTRACT

The effects of backscattering upon self-absorption correction curves are demonstrated. Data are given for the backscattering powers of several substances for the beta radiations from C^{14} , and for self-absorption of samples of barium carbonate and wax, containing C^{14} , mounted on aluminum.

*This paper is based upon work performed under contract No. W-7405-Eng.-48 with the Atomic Energy Commission in connection with the Radiation Laboratory, University of California, Berkeley.

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THE RELATION OF BACKSCATTERING TO SELF-ABSORPTION

By

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12 January 1948

Part I

Backscattering, or reflection, directs into the detector particles whose original directions were not such that they would have passed through the sensitive volume. By far the greatest component of the backscattered radiation is due to particles originally directed away from the detector, only a relatively small number being detected which were directed in the same general direction as the sensitive region of the counting system. The magnitude of the effect is therefore dependent upon the nature of the sample and sample mounting as well as upon the particle energy; the effect observed increases with increasing atomic number of the mount and with increasing particle energy. The contribution due to the sample materials can be neglected if the observed activities are corrected for self-absorption by the use of a method where data are obtained by extrapolating observed specific activities to zero sample thickness (1). The mounting effect can be kept small by the use of supports containing the lighter elements, such as paper,

* This paper is based on work performed under contract No. W-7405-Eng.-48 with the Atomic Energy Commission in connection with the Radiation Laboratory, University of California, Berkeley.

(1) P. E. Yankwich, T. H. Norris and J. Huston, Anal. Chem. 19, 439 (1947);
P. E. Yankwich, Report CC-3567.

glass, aluminum, beryllium, quartz, cellophane, nylon, etc.

Accurate determinations of backscattering factors as a function of the solid angle subtended by the detector at the source have not been made. It is known that the magnitude of the effect observed is dependent upon the geometry of the detection system, increasing with increasing geometric efficiency. In order to gain information on the effect of backscattering upon self-absorption correction data, some experiments were performed which were designed to yield information concerning the relative backscattering powers of a number of substances at two different detection geometries.

A 4 microgram sample of C^{14} active barium carbonate was mounted over an area of 0.040 cm^2 on a plastic film 0.08 mg/cm^2 thick; the sample particle layer was not thicker than 0.15 mg/cm^2 . The equivalent thickness of the counter window and air path was 3.4 mg/cm^2 at the lower (12 percent) geometry, 2.3 mg/cm^2 at the higher (36 percent). The sample was first counted over 25 cm of air; then thick layers of various materials were maneuvered to within 0.05 mm of the back of the sample spot and the activity again observed. This enhanced activity divided by that first observed is equal to the backscattering (reflecting) factor of the substance of the thick layer at the geometric efficiency with which detection was made. The data are collected in Table 1.

With these data it is possible to make certain statements about a phenomenon involving multiple scattering of beta particles from within sample materials. (For convenience in discussion backscattering from the sample mount will be called "external reflection", while that from the sample itself will be called "internal reflection".) Consider first a sample of radioactive barium carbonate mounted on aluminum and counted at 36 percent

Table 1
Backscattering of C^{14} Beta-particles

scatterer	relative observed activity (backscattering factor or reflection coefficient)	
	12% geometry	36% geometry
air	1.00	1.00
platinum	1.43 ± 0.02	1.51 ± 0.02
barium carbonate	$1.30 \pm .01$	$1.35 \pm .01$
glass	$1.16 \pm .01$	$1.17 \pm .01$
aluminum	$1.15 \pm .01$	$1.16 \pm .01$
paper(unsized)	$1.04 \pm .015$	$1.07 \pm .015$
wax(artificial ceresin)	$1.04 \pm .015$	$1.07 \pm .015$

geometry. If one envisions the sample as made up of many thin layers it is seen that the observable activity of the first lamina is 1.16 times its true observable activity (2) because the aluminum mount contributes an additional radiation flux to the measurement by external reflection. The activity observable from the next lamina is increased by slightly more than 1.16 for although fewer radiations can reach the mount, these are more powerfully reflected from the first barium carbonate lamina. Thus as the sample thickness is increased the activity observed rises from 1.16 to 1.35 times that expected when all reflection processes are neglected.

If a sample of active wax were used the activity observable would fall from 1.16 to 1.07 times that expected because the internal reflecting power of wax is less than the external reflecting power of aluminum. It must be emphasized that these reflection effects are seldom noted directly, but are impressed upon the experimental self-absorption relations. For this reason all backscattering effects, at least insofar as they affect self-absorption corrections, are cancelled out when the self-absorption correction curves are derived from data obtained experimentally under conditions identical with those which will be used in routine counting.

Backscattering effects saturate very rapidly because they involve double transit of radiations through absorbing layers, and the effect of the weak radiations is thus emphasized. For example, the maximum penetration of C^{14} beta particles in matter is about 28 mg/cm² yet the reflection effects reach 80 percent of their maximum at a sample thickness of 6 mg/cm², and 97 percent at 12 mg/cm².

(2) The true observable activity is here defined as the actual disintegration rate of the sample multiplied by the overall detection efficiency of the counter after correction for absorption effects.

Several authors (3) have given values for the absorption coefficient of the C^{14} beta radiation. These values are usually derived from the slope at zero sample thickness of a plot of activity observed against thickness of sample layer, or from the slope at zero absorber thickness of an ordinary absorption curve (usually in aluminum). The result quoted in the first paper was accompanied by no experimental data relative to reflection effects; that in the second was obtained from samples mounted on aluminum, in the third from a curve derived from counting data with sources mounted on stainless steel (whose reflecting power is near that of aluminum). The effect of backscattering processes is to make the absorption coefficient including reflection processes smaller than the absorption coefficient including only absorption processes by an amount determinable from the reflection coefficient of the mount; thus in the second research cited, at least, the absorption coefficient (no backscattering processes being considered) is $[0.285 \pm 0.008] [1.16 \pm 0.01]$, or $0.331 \pm 0.010 \text{ cm}^2/\text{mg}$, at 36 percent geometry.

It has been tacitly assumed by many investigators that the self-absorption corrections for many sample substances are the same as those for barium carbonate, with which most such determinations have been made. That this is not the case can be seen by reference to Figure 1, where data for wax and barium carbonate samples, both mounted on aluminum, are graphed. The active wax was prepared by dissolving in a large amount of artificial ceresin wax a small amount of p-phenylphenacylacetate prepared from methyl-labelled sodium acetate.

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- (3) A. F. Reid, J. R. Dunning, S. Weinhouse and A. V. Grosse, Phys. Rev. 70, 431 (1946), $0.257 \text{ cm}^2/\text{gm}$; P. E. Yankwich, T. H. Norris and J. Huston, Anal. Chem. 19, 439 (1947), $0.285 \pm 0.008 \text{ cm}^2/\text{mg}$; A. K. Solomon, R. G. Gould and C. B. Anfinsen, Phys. Rev. 72, 1097 (1947), $0.29 \text{ cm}^2/\text{mg}$.
-

Figure 1. Self-absorption Correction Curves for Barium Carbonate(upper curve) and Ceresin Wax (lower curve), Mounted on Aluminum.

A consideration of the reflection enhancement of the observed radiation leads one to conclude that at sample thicknesses where the backscattering effects are saturated the two curves will be related to each other by the quotient of their reflection coefficients; the value predicted is $1.35 \quad 0.01 \quad 1.07 \quad 0.015 = 1.26 \quad 0.02$, that observed is 1.27

In Table 2 are collected the values derived from Figure 1 for the activity thickness and specific-activity-thickness curves of barium carbonate and wax mounted on aluminum.

Part II

Dr. L. R. Henrich of the Theoretical Group has developed an equation to account for these reflection effects for various combinations of sample and mounting substances. The development of the equation assumes that of the radiation incident upon a thin layer a constant fraction is transmitted and a different fraction reflected. Integration over a sample of definite thickness on a mount of "infinite thickness" gives the following relation for the Fraction of Maximum True Specific Activity as a function of sample thickness:

$$\left(\frac{1+p_1}{\mu x} \right) \left(1 - e^{-\mu x} \frac{(1 - p_1 p_2) - (p_1 - p_2) e^{-\mu x}}{(1 - p_1 p_2) - p_1(p_1 - p_2) e^{-2\mu x}} \right)$$

μ is the absorption coefficient corrected for reflection processes, 0.331, p_1 is the reflecting power of the sample material (reflection coefficient minus 1), while p_2 is that of the mount.

For both the combinations shown in Figure 1 the equation yields curves which bow above those derived from experiment.

Table 2

Self-absorption Data for Barium Carbonate and Wax

Mounted on Aluminum (30% geometric efficiency)

Sample Thickness mg/cm ²	Fraction of Max. Observable Activity		Fraction of Max. Obser Specific Activity	
	BaCO ₃	Wax	BaCO ₃	Wax
0	0.000	0.000	1.000	1.000
1	.245	.301	.856	.823
2	.431	.480	.761	.656
3	.560	.602	.660	.548
4	.663	.695	.586	.475
5	.745	.762	.527	.416
6	.807	.820	.475	.373
7	.854	.860	.431	.336
8	.887	.898	.392	.307
9	.914	.933	.359	.283
10	.934	.944	.330	.258
11	.947	.955	.304	.237
12	.957	.966	.282	.220
13	.965	.973	.262	.205
14	.973	.981	.246	.192
15	.978	.985	.230	.179
16	.983	.988	.217	.169
17	.987	.992	.205	.160
18	.990	.995	.194	.151
19	.993	.996	.185	.143
20	.995	.997	.176	.136

In the case of the barium carbonate curve the maximum difference, about 8 percent, is at about 4 mg/cm^2 ; the derivation at sample thicknesses greater than 8 mg/cm^2 is less than 3 - 4 percent. The wax data are similarly approximated. This agreement is rather fair since angular effects in the scattering were completely ignored and no attempt was made to include corrections for the relatively higher energy of the scattered radiation. A more refined treatment of the problem is being worked on.