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CONTRIBUTION TO THE DETERMINATION OF TOTAL COEFFICIENTS OF BETA BACKSCATTERING

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INTRODUCTION

Backscattering of beta rays from a certain material is expressed with the help of a backscattering coefficient, which is defined in counting methods as the ratio of backscattered beta particles related to a certain geometry to the number of beta particles fallen on the surface of the scattering material.

By compiling recent experimental results of the study of beta radiation backscattering and through their mutual comparison it is possible to find out that the results of various authors are sometimes contradictory. In some cases fully contradictory results were obtained, e. g. in the study of the dependence of beta rays backscattering coefficients on the energy of the original radiation.

Total backscattering coefficients can be determined from the complete spectrum of the original and backscattered radiation. In practice, it is not possible to obtain such experimental conditions, where all particles in the whole spectrum range could be detected. For various reasons low energy radiation is not detected and therefore its ratio of total backscattering coefficient cannot be measured directly.

The prevailing part of measurements for the determination of backscattering coefficients for detection geometry $\ll 2\pi$ *sr* was carried out up to this time using *G-M* counter. Very soft beta particles are not detected because they are absorbed in the air layer and counter window. Some authors did not correct the results obtained by measurement [1], others carried out a correction based on extrapolation of absorption curves to the zero value of absorber thickness [2—5].

Using a scintillation counter [6—7] it is not possible to record the complete spectrum due to the photomultiplier background in the low discrimination voltage values, and also due to non-linearity of the light yield dependence on the energy of particles in the low values range. Thus, correction based on extrapolation of discrimination curves to zero energy was made.

Backscattering coefficients were mainly determined up to this time for the radiation geometry of isotropic source, at which the source of radiation is placed directly on the scattering material, or only a thin film is placed between the radiation source and the scattering material, in order to avoid the hardly checkable surface effects which can occur in the case when the radionuclide is placed directly on the scatterer. Part of very soft beta particles are in this case absorbed both by carrier film and the radiation source itself.

In our previous papers [6—7] the assumption was expressed that correction for the absorption based on extrapolation of absorption curves using *G-M* counter detection is not sufficient, in consequence of which lower values of backscattering coefficients are obtained. The present paper is devoted to a more detailed study of this problem. Possibilities of the correct backscattering coefficient values using both detection methods mentioned above are investigated and discussed.

EXPERIMENTAL

Two experimental arrangements were used. Radiation geometry of isotropic source and detection geometry 1 sr (about 65°) were used in both cases. Discrimination curves of original and total (original + backscattered) radiation were plotted by the scintillation method. Total counts were obtained by means of their extrapolation to the zero energy point and total backscattering coefficients were computed. Measurement conditions were essentially improved by the cooling photomultiplier and using the vacuum chamber. Discrimination curves were plotted under normal pressure, when the air layer between the radiation source and scintillator was 1.47 mg/cm^2 and at vacuum .2 torr when the air layer was lowered to .4 μg/cm^2 and therefore can be neglected. Measuring equipment was calibrated in order to determine the zero point and for the purpose of determining the energy scale of discrimination curves. This measuring method, experimental arrangement, and also experimental conditions are described in detail in our previous papers [6, 7].

A similar geometric arrangement to the one above was used in measurements with *G-M* counter and is described in Fig. 1. The total mass thickness

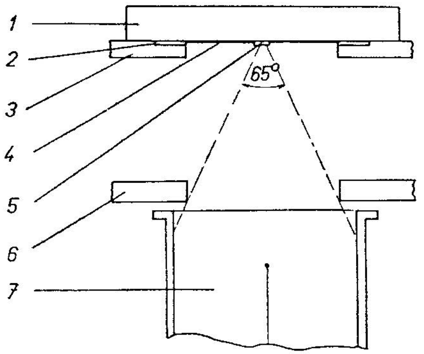

Fig. 1. Illustration of geometric arrangement for measurements with G-*M* counter. 1 — scattering material, 2 — carrier ring, 3 — carrier board, 4 — thin carrier film, 5 — radiation source, 6 — screen, 7 — G-M counter

of the counter window together with air layer was 4.19 mg/cm^2. Measuring equipment Messplatz VA-G-20 was used for the counts registration. An electronic member was placed into the circuit in order to keep the constant equipment dead time. Measurements were carried out with relative square error .31 % (10^5 registered counts). Radionuclides ^{35}S ($E_{\max} = .168$ MeV), ^{204}Tl ($E_{\max} = .771$ MeV) and ^{32}P ($E_{\max} = 1.710$ MeV) were used as beta radiation sources. Sample preparation was carried out by placing and evaporating solutions containing the above mentioned radionuclides on thin films (10—20 μg/cm^2). Aluminium, paladium and platinum were used as scatterers. In all cases their thickness exceeded the saturated backscattering thickness and their surfaces were carefully polished before use.

Results were not corrected for absorption in the source itself and carrier film, because this absorption takes place in the same ratio in both detection methods.

RESULTS AND DISCUSSION

A very strong absorption effect on the backscattering coefficient value, already in relatively thin absorber thicknesses, was found by measurements of discrimination curves under normal pressure and in vacuum. In Fig. 2 can be seen the effect of the air layer with mass thickness 1.47 mg/cm^2 found between the scintillator and radiation source, on the course of discrimination curves for both the original radiation of radionuclides ^{35}S and the total radiation for Al and Pt as scatterers. The decrease of backscattering value as a result of absorption in the air layer was counted from extrapolation counts. For comparison purposes, measurements were made with *G-M* counter under equal geometric conditions, by which absorption curves illustrated in Fig. 3 were obtained. On their basis, backscattering coefficients corresponding to the mass thickness of the absorbing layer 0, 1.47 and 4.19 mg/cm^2 were calculated.

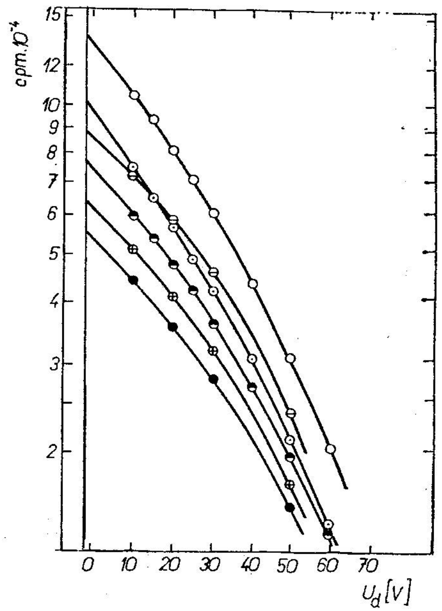

Fig. 2. Discrimination curves of original radiation ^{35}S and total radiation (original + backscattered) for Pt an Al taken in vacuum and under normal pressure (absorber thickness 1.47 mg/cm^2) in detection geometry 1 sr.
● original radiation ^{35}S under normal pressure, ◓ original radiation ^{35}S in vacuum, ⊕ original + backscattered (Al) radiation under normal pressure, ⊙ original + backscattered (Al) radiation in vacuum, ⊖ original + backscattered (Pt) radiation under normal pressure, ○ Original + backscattered (Pt) radiation in vacuum.

The results obtained by both detection methods are summarized in Table 1 in the form of backscattering coefficients and their absolute and relative decrease as a result of absorption. The values given in the Table show a relatively good agreement between the backscattering coefficients obtained by measuring with the scintillation and *G-M* counter, the absorbing layer being the same, i. e. 1.47/cm^2. It is rather striking that the backscattering coefficients, obtained my measuring in vacuum using scintillation counter, have much higher values than those obtained by extrapolating absorption curves to zero absorber thickness, using *G-M* counter. It can also be seen by comparing

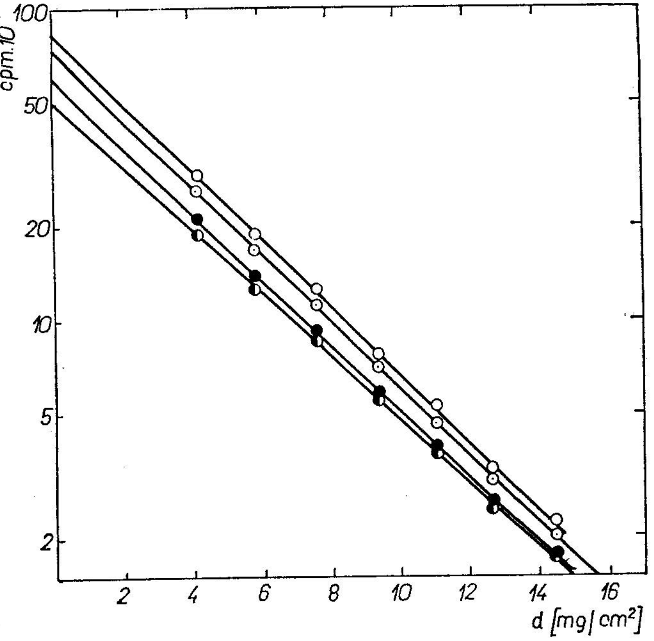

Fig. 3. Absorption curves of original and total radiation (original + backscattered) for ^{35}S in detection geometry 1 sr.
◐ original radiation, ● original + backscattered (Al) radiation, ⊙ original + backscattered (Pd) radiation, ○ original + backscettered (Pt) radiation.

the relative count increase in the individual radiation sources. By direct measurement in vacuum with scintillation counter, it was found, that by the removal of the air layer, the counting rate of backscattered radiation is increased by 85.5 % for Pt and 188.0 % for Al, while by extrapolation of absorption curves in the range of absorber thickness 0—1.47 mg/cm², a relative increase of 50.0 % for Pt and 58.4 % for Al is obtained.

Table 1

Backscattering coefficients ^{35}S obtained using scintillation counter on the basis of extrapolation of discrimination curves plotted in vacuum and under normal pressure and backscattering coefficients obtained using *G-M* counter on the basis of extrapolation of absorption curves.

Scattering material	Measured with scintilation counter			Measured with *G-M* counter			
	backscattering coefficient		relative increase [%]	backscattering coefficient			relative increase by extrapolation 1.47—0 mg/cm² [%]
	absorber thickness 1.47 mg/ /cm²	in vacuum		absorber thickness 4.19 mg/cm²	absorber thickness 1.47 mg/cm²	absorber thickness 0 mg/cm²	
Al	.161	.285	77.5	.117	.153	.186	21.5
Pt	.590	.775	31.4	.535	.584	.666	14.0

The comparison of the results obtained supports the assumption [6,7] that the absorption correction on the basis of extrapolation of absorption curves is inadequate. Absorption curves are usually extrapolated in the range of some mg/cm², in the majority of cases more than 3 mg/cm², because the absorber thickness formed by the counter window and air can only seldom be lowered under this value. Extrapolation takes place in the semilogarithm scale on the basis of curvature, such as have regression absorption curves obtained from experimental data, which may be seen from Fig. 3.

By direct measurement in vacuum, expecially in backscattered radiation, a substantially greater drop in the count rate was registered than the one obtained with the help of extrapolation of absorption curves. This difference greatly increases from Pt to Al. This fact proves that absorption curves have in the range of very small absorber thicknesses, another and substantially greater down-grade than in greater thicknesses.

This character of absorbing curve in the range of small absorber thicknesses also comes from the course of backscattered beta radiation spectra and from the relation between the energy of electrons and their range.

Experimental differential spectra of backscattered beta radiation [8,9] can be approximated for the scatterers with high atomic numbers through the linear function

$$N(E) = N(0)\,(E_{rm} - E) \qquad (1)$$

and for scatterers with a lower atomic number through the exponential function

$$N(E) = N(0)\,\mathrm{e}^{-kE}, \qquad (2)$$

where $N(E)$ is the number of particles with energy E, $N(0)$ the number of particles with energy E limiting to 0, E_{rm} is quasi the maximum energy of backscattered beta radiation and k is a constant. In the case of the linear course of the differential spectrum the integral spectra can then be expressed by

$$\mathrm{I}_i(E) = N(0)\,(0{,}5\,E_{rm}^2\,E + 0{,}5\,E^2) \qquad (3)$$

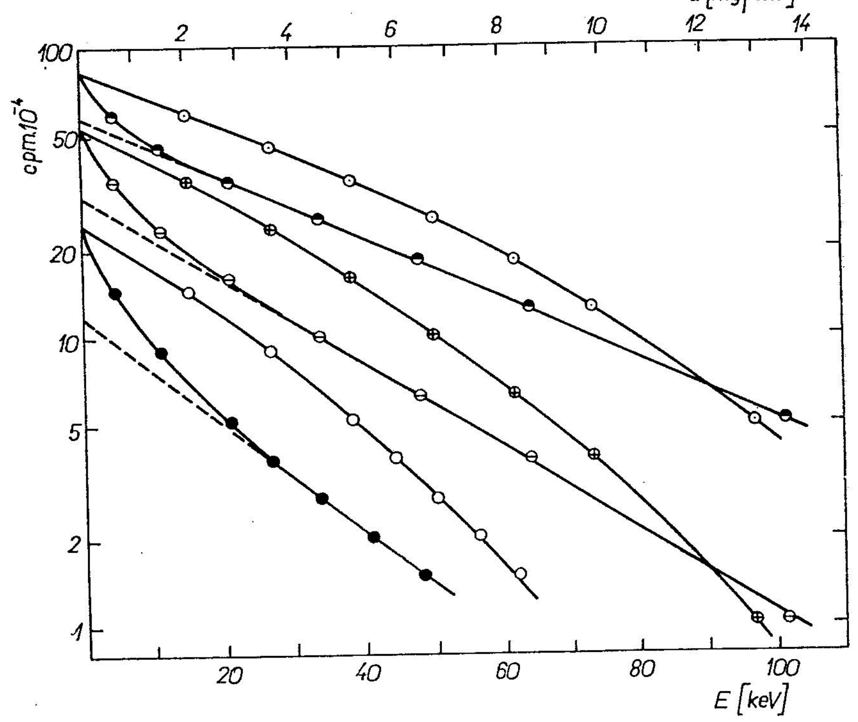

Fig. 4. Course of integral spectra and quasi absorption curves for original radiation ^{35}S (○, ◓) and for backscattered radiation from Pd (⊕, ⊖) and Al (○, ●).

and in the case of exponential course of differential spectrum by

$$\mathrm{I}_e(E) = \frac{N(0)}{k}\,(\mathrm{e}^{-kE} - \mathrm{e}^{-kE_{rm}}). \tag{4}$$

In agreement with relations (3) and (4) is also the course of our experimental integral spectra which were obtained by plotting discrimination curves and by expressing discrimination voltage in terms of energy on the basis of the performed calibration.

After transforming energy in integral spectra to range $R_{\max}$ with the help of relation joining the energy of particles with stopping thickness, a steep down-grade of a quasi absorption curve should be obtained for very low values of absober thickness. It is connected with the fact that the range of electrons is very small for low energies and it is steeply rising with increasing energy, because energy losses through unelastic scattering rapidly drop with energy increase. In the range of higher energy the stopping thickness of electrons increases with energy approximately according to linear dependence. This is pointed to by transforming integral spectra to quasi absorption curves with the help of expressing energy in range according to the relation

$$R_{\max} = .67\,E^{5/3}, \tag{5}$$

which is valid for $E < .2$ MeV (10). The transformation of the original radiation ^{35}S and backscattered radiation from Al and Pt is as an example illustrated in Fig. 4.

The comparison of the course of integral spectra and quasi absorption curves points to the fact that the change of the character of a quasi absorption curve is of great importance in the range of low absorber thickness with the result that in making the absorption correction on the basis of extrapolation of absorption curves it is not possible to get the correct values of beta radiation backscattering coefficients. In general the extrapolation counts thus obtained are smaller than the real total counts. To what extent this effect is made use of, depends on the nature of the energy spectrum of detected radiation. It is therefore made use of to a different extent for various kinds of original radiation and as a result of great changes in energy distribution of the original radiation in backscattering and its strong dependence on the atomic number of the scatterer, it is made use of to a different extent even in the same original radiation but in scatterers with different atomic numbers.

Table 2 gives the percentage decrease of extrapolation counts as a consequence of transforming integral spectra to quasi absorption curves using relation (5) when their real course in the range $d < 4$ mg/cm^2 is not taken into consideration. From these data, it is obvious that the significance of this effect increases with the decreasing energy of the original radiation and with the decrease of the atomic number of the scatterer.

The transformation computing was on the assumption that only particles with a certain energy E_1 can be absorbed by some absorber thickness R_1 for which this thickness is the stopping thickness. If it were taken into consideration that this thickness absorbs a certain amount of particles with energy $E > E_1$, as it is in reality, then the absorption curve obtained in this way should have a somewhat steeper down-grade, especially in its beginning. Besides that, it can be admitted, that relation (5) used for the transformation, does not fully bring out the real dependence of the range on the energy.

These error sources bring into the transformation certain inaccuracies (therefore only a „quasi" absorption curve) which, however, for the inter-

Table 2

Relative decrease of extrapolation counts as a result of transforming integral spectra to quasi absorption curves.

Radionuclide	Relative decrease [%]		
	original radiation	backscattered from Pd	backscattered from Al
^{32}P	2.5	5.9	9.9
^{204}Tl	9.2	11.7	15.5
^{35}S	28.8	37.8	52.5

Table 3

Backscattering coefficients for ^{35}S calculated on the basis of the course of absorption curve obtained by measurement using G-M counter and backscattering coefficients calculated from the course of quasi absorption curve obtained by transforming integral spectra.

Scattering material	Measured absorption curves		Quasi absorption curves	
	absorber thickness 4.19 mg/cm^2	absorber thickness 0 mg/cm^2	absorber thickness 4.19 mg/cm^2	absorber thickness 0 mg/cm^2
Al	.117	.186	.113	.198
Fe	.210	.314	.232	.350
Pd	.395	.495	.400	.517
Pt	.535	.666	.583	.681

pretation of the considered effect, cannot be of great significance. This is supported by a relatively good agreement of backscattering coefficients, computed on the basis of the course of absorption curves obtained by measurement using *G-M* counter (Fig. 3) and backscattering coefficients computed from the course of quasi absorption curves obtained by transforming integral spectra (Fig. 4), what is evident from the comparison of backscattering coefficients for equal absorber thickness given in Table 3.

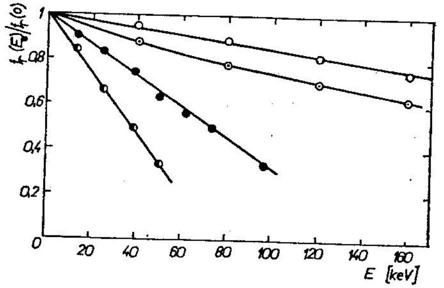

Fig. 5. Dependence of relative backscattering coefficient $f_r(E_e)/f_r(0)$ on the energy of particles E_e eliminated in detection with the help of discriminator.
◐ ^{35}S, Al; ● ^{35}S, Pd; ⊙ ^{204}Tl, Al; ○ ^{204}Tl, Pd.

In Fig. 5 is illustrated the dependence of the relative backscattering coefficients $f_r(E_e)/f_r(0)$ on the energy value of particles E_e eliminated at detection with the help of a discriminator. The softer the original radiation and the lower the atomic number of the scattering material, the greater the decrease of the backscattering coefficients with the energy of eliminated particles. From the diagrams in Fig. 5 can be seen that in the case of very soft original radiation and low atomic number of the scattering material there occurs a marked decrease of backscattering coefficients even in very low energy of particles eliminated at detection.

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