The Backscattering of Beta-Rays

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The backscattering of β-rays has been observed using an end-window G-M counter with a thin mica window as a detector. Backscattering growth curves of β-rays of C^{11}, S^{35}, Na^{22}, I^{131} and P^{32} have been obtained for aluminium backings. The saturation backscattering factor for these β-rays as a function of atomic number of backscatterers and as a function of maximum β-ray energy for several backscatterers has also been obtained. The fact that electrons are backscattered to a great extent than positrons has been established. The angular distribution of backscattered β-rays of Na^{22}, Sr^{89} and I^{131} was measured with some interesting results. A few brief accounts are presented for the present observations in comparison with those obtained by other workers.

I. INTRODUCTION

For most of the works with radioactive tracers there is no need to know the absolute activity of samples, and, in general, relative-activity measurements are sufficient. However, it is often necessary to estimate the absolute number of radioactive nuclei, for instance, in the determination of cross sections of nuclear reactions, the determination of radioactive decay constants, and in the field of the radiochemical analysis it is often required to determine the absolute quantity of the radioactive elements in a sample.

The observed counting rate of a β emitter relative to the absolute rate of disintegrations depends upon several factors of the meaurement; an expression of the counting rate may be written as the product of the disintegration rate, the geometrical efficiency, the correction factor concerning the counting loss due to the finite resolving time of the G-M tube and scaler, and a number of correction factors expressing the effects of absorption and scattering of β-particles. An expression containing such various correction factors has been given by Zumwalt[1]. Among these factors that for the backscattering of β-rays by the materials supporting the source seems to be one of the most influential one for the absolute β counting. The backscattering of β-rays has so far been studied experimentally by several workers[1~7] and theoretically by Bethe *et al.*[8] and by Bothe.[9] Seliger[10,11] have recently reported the experimental work on the backscattering of positrons with some interesting results. However, some discrepancies remain in these results, owing to the different conditions of experimental arrangements.

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It is the purpose of the present paper to give some data on the backscattering of β-particles which have been obtained under somewhat improved conditions in connection with the work on absolute β counting carried out in our laboratory, and particularly, we want to report on the results concerning the angular distribution of scattered β-rays, since there has been relatively little experimental work on this effect.

II. EXPERIMENTAL PROCEDURES

The geometry of the present measurement is shown schematically in Fig. 1. An end-window G–M tube used was filled with argon and alcohol at a pressure of 9 and 1 cm Hg, respectively. The thickness of the mica window was 2.8 mg/cm^2 and the diameter of the cylindrical cathode was 2.2 cm.

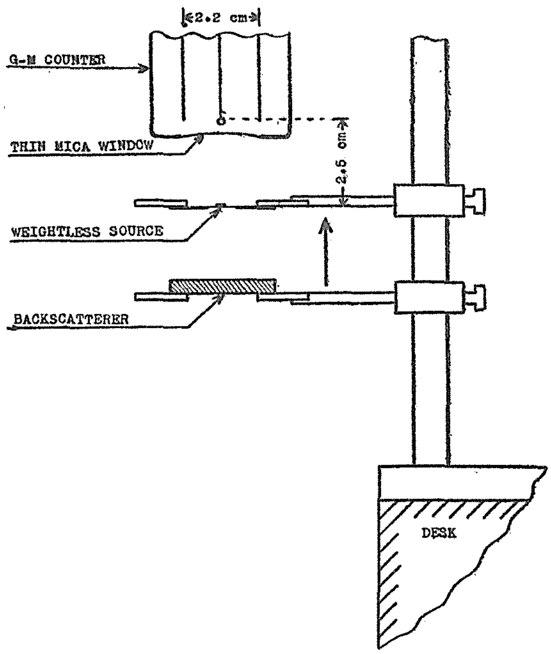

Fig. 1. Schematic drawing of geometrical arrangement of apparatus to measure backscattering of β-rays.

Each sample was mounted on a very thin film of collodion or zapon (10$\sim$100 μg/cm^2), which covered an aperture of about 1 cm in diameter on a thin mica sheet cemeted on the lower surface of an aluminium ring. The sample was mounted on the film in the form of a solution and allowed to be evaporated so that it could be considered to be practically weightless, and its dimension to be approximately a point source. By this procedure the backscattering from the source supporter and the self-absorption and self-scattering in the source could be neglected. The backing material was lifted up as closely as possible to the source, which was 2.5 cm below the counter in all the measurements as shown in Fig. 1. It is noteworthy that, in the present experiment, the sample housing box was not used to avoid the scattering, which may occur from the box walls.

The increase in counting rate due to the backscattering was measured by observation of the counting rate with and without the backing materials. The backscattering factor was defined as the ratio of the counting rate with a backing to that without it. In the present work, a standard scale-of-64 scaler circuit with a mechanical register was used. In our all fignres probable errors are not shown because they were less than one percent owing to sufficient counting rates. The β emitters used have the characteristics listed in Table 1.

Table 1. Chracteristics of β emitters.

Emitter	Half-life	Maximum energy of β-rays, Mev
C^{14}	5568 y	0.154
Na^{22}	2.60 y	0.575 (β^+)
P^{32}	14.5 d	1.701
S^{35}	87.1 d	0.167
Ca^{45}	152 d	0.254
Sr^{89}	54 d	1.463
I^{131}	8.04 d	0.608 (87.2%), 0.335(9.3%)

III. BACKSCATTERING FACTORS

The effect of thickness of the backing for β-rays of C^{14}, S^{35}, Ca^{45}, I^{131}, and P^{32}, using aluminium as backscatterers, is shown in Fig. 2. The counting rate increases with thickness of the backing and reaches a saturation value at a range corresponding to about one-fifth of the maximum range of β-rays in the substance. This condition is often called "saturation backscattering". Several workers have observed that the approximate saturation was attained in the region of thickness from about one-fourth to one-eighth of the maximum range of the given β-rays.

The mass thickness for saturation backscattering is independent of the atomic mumber of backing materials, Z, but the value of the saturation backscattering facter is a critical function of Z and of the maximum energy of the β-rays. In Fig. 3 is shown the relation of this factor against Z of the thick backing materials. From this result it can be seen that the factor increases monotonously with Z of backscatterers. Our results are in agreement within a few percent with the results obtained by Zumwalt[3], Tobias[6], and Burtt[2], using the β-rays of P^{32}, nevertheless a slight difference observed between these results may be due to the difference in the counting arrangement.

A plot of the saturation backscattering factor for several backings is shown in Fig. 4 as a function of maximum β energy. The result shows that the factor decreases when the energy is below 0.6 Mev and is independent of the energy above this value. Engelkemeir[5] reported that the above-mentioned independency is observ-

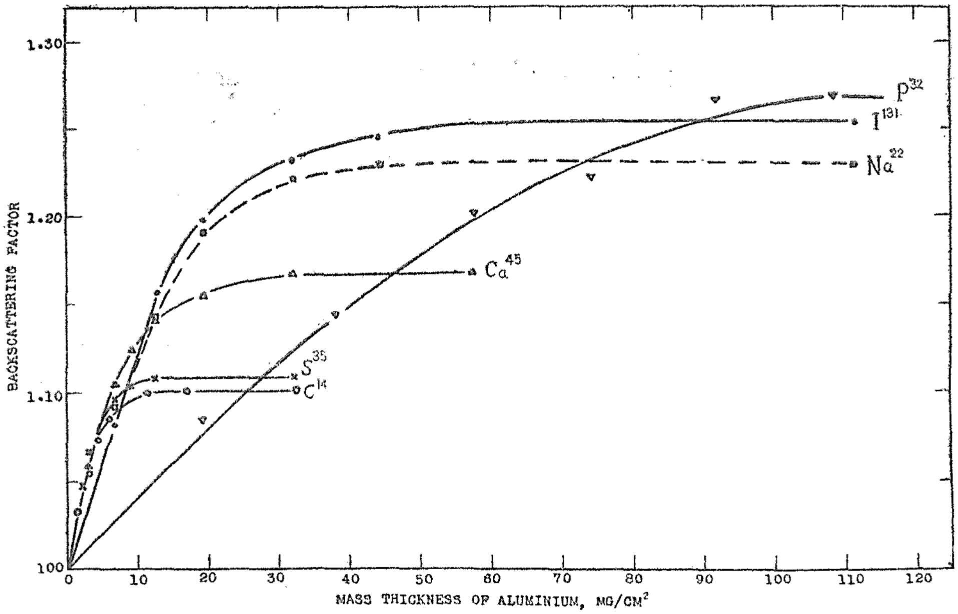

Fig. 2. Backscattering growth curves of β-rays of C^{14}, S^{35}, Ca^{45}, Na^{22}, I^{131}, and P^{32} obtained with aluminium backing ($Z=13$)

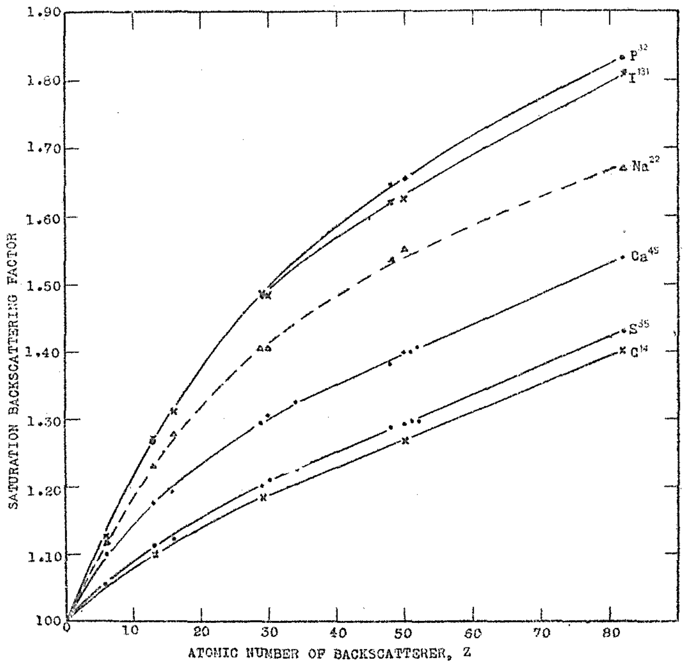

Fig. 3. Saturaction backscattering factor as a function of atomic number of backscatterer.

ed from 1.0 to 2.5 Mev, while Burtt[2] observed that it is found from 0.6 to 1.7 Mev and his results are in good agreement with those obtained by the present experi-

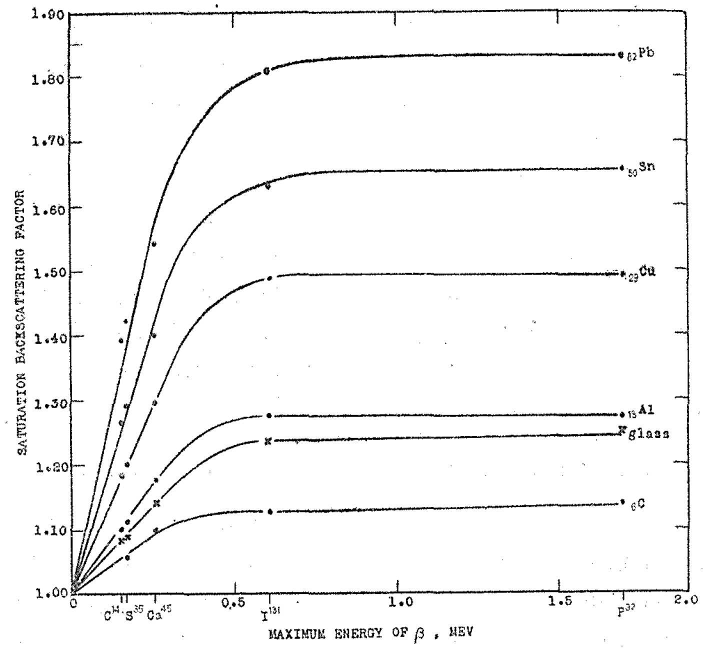

Fig. 4. Saturation backscattering factor as a function of maximum β energy for several backscatterers.

ment. The backscattering factor decreases with the energy of the β-rays in the energy region below a certain value seems to be due to the fact that the energy of backscattered radiation is weaker than unscattered radiation and to the fact that the absorption in the air between the source and the G-M tube and the absorption in the window of the tube are increasingly large with decreasing β energy. After the correction for the decrease in counting rate due to such absorption effect was carried out, Zumwalt[5] showed that the saturation backscattering factor does not depend greatly on the energy of β-rays, at least in the range of 0.3 to 1.7 Mev. Furthermore, in this connection, it may be interesting to note, that Schonland[12] found the backscattering of monochromatic electrons of energies from 10 to 90 Kev to be substantially independent of energy.

IV. BACKSCATTERING OF β^+-RAYS

Some workers have published the positive β-ray scattering, especially Seliger[10,11] has recently reported the experimental studies on this phenomenon with some interesting results. We observed the backscattering of the β^+-rays of Na^{22} in the same manner as negative β-rays mentioned above, but in this case some precautions were taken against the γ-ray background. The dashed lines in Fig. 2 and 3 show the results obtained for the β^+-rays of Na^{22}.

From the curves obtained it appears that the backscattering of β^+-rays shows the same tendency as those of β^--rays, however, it is noticeable that the value of the backscattering factor for the β^+-rays of Na^{22} is considerably lower in comparison with that for the β^--rays of I^{131}, although maximum energies of both β-rays are nearly equal. The annihilation of positrons can not account for the fact, since it may give only 1 or 2 per cent difference according to the theory of Heitler[13]. Miller[14] has calculated the ratio of the backscattering coefficients, β^-/β^+, using the theoretical cross-sections for single scattering as given by Bartlett and Watson[15] for electrons and Massey[16] for positrons. Miller estimated $\beta^-/\beta^+=1.16$ for $_{80}Hg$ as a backing, while the experimental result by Seliger was $\beta^-/\beta^+=1.3$ for $Z=80$. From our measurement the ratio β^-/β^+ is estimated as 1.21 for $Z=80$, which is in fair agreement with Miller's value. At any rate, an excess of β^--ray backscattering over β^+-ray backscattering seems to be expected.

V. ANGULAR DISTRIBUTION OF BACKSCATTERED β-RAYS*

Backscattering factors are, by rough measurements, found to depend on the experimental arrangement, and especially on the distance between the source and the detector. This fact may be explained as to be due to the anisotropy of the angular distribution of the scattered β-rays emanating from the backscatterer.

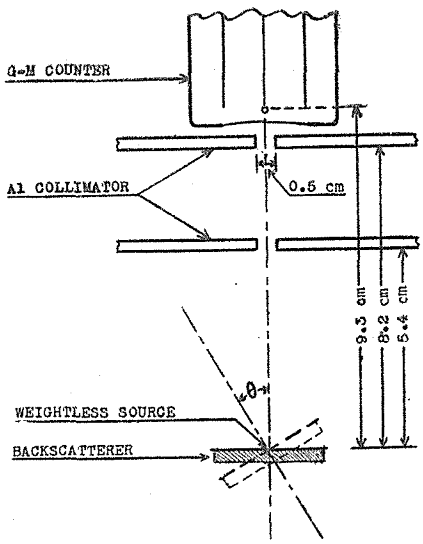

Fig. 5. Schematic drawing of geometrical arrangement of apparatus to measure angular distribution of backscattered β-rays.

Then, the angular distribution of the scattered radiation has been determined

* A preliminary report of this work was read before the semi-annual meeting of the Institute for Chemical Research, University of Kyoto, on June 7th, 1952.

using the special arrangement of the apparatus shown schematically in Fig. 5. The G-M counter used and the method of the preparation of samples were the same as mentioned in Section II. The β-ray source was maintained at a constant distance from the counter window and on the axis of the counter. Between the counter and the source a set of two aluminium collimators of 3 mm thickness was placed, as shown in Fig. 5, in order to limit the flux of the scattered radiation. The source supporter can be rotated so that it intersects the axis of the counter at various angles. Several metals used as backings were placed as closely as possible behind the film supporting the source at each angle of the measurement. If an angle θ is defined as the angle between the axis of the counter and the normal of the plane containing the film, then in the arrangement shown by dotted lines in Fig. 5, for instance, θ is 30°.

The angular distribution of the scattered radiation was measured by observations of the counting rate with and without the backing behind the film supporting the seurce at each angle. Since a slight asymmetry in the angular distribution observed for both radiations with and without the backing seemed to be due to the difficulty in exact centering and finite spread of the source of about 3 mm in diameter, the average of the values for plus and minus θ was taken to eliminate this effect.

The angular distribution of the backscattering factor for Sr^{89} β-rays with aluminium backings of various thickness is shown in Fig. 6, while in Fig. 7 the factor

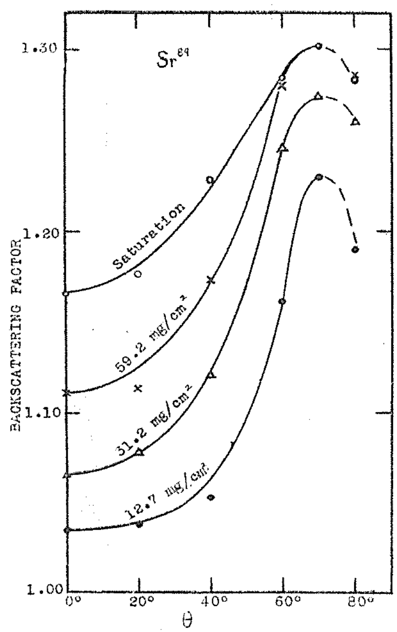

Fig. 6. Angular distribution of the backscattering factor for β-rays of Sr^{89} with aluminium backings.

is given as a function of thickness of the aluminium backing. The angular distributions of the saturation backscattering factors for Sr^{89}, I^{131}, and Na^{22} with several

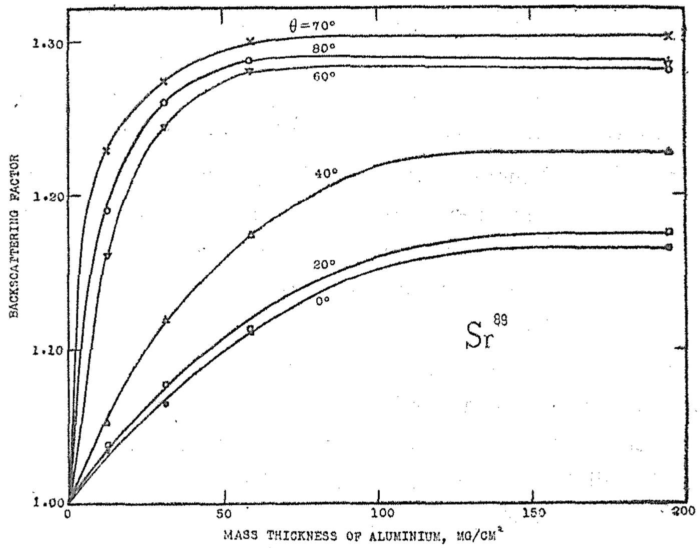

Fig. 7. Backscattering factors as fuctions of thickness of the aluminium backing for β-rays of Sr^{89}.

backings are shown in Figs. 8, 10, and 12, respectively, and in Figs. 9, 11, and 13,

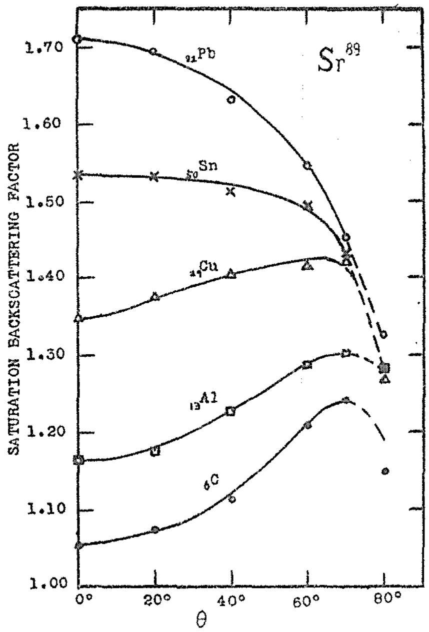

Fig. 8. Angular distribution of the saturation backscattering factor for β-rays of Sr^{89} with several backings.

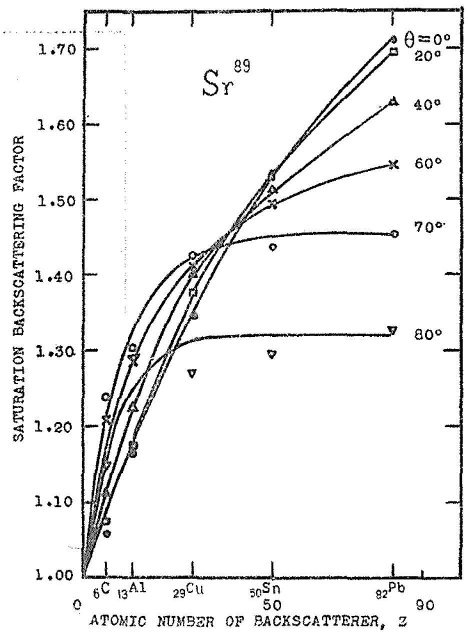

Fig. 9. Saturation backscattering factor for β-rays of Sr^{89} as a function of atomic number of backscatterer.

are shown the factors with each source as fuctions of Z of backing elements for $\theta=0°$, 20°, 40°, 60°, 70°, and 80°. The measured data at $\theta=80°$ contain some ambiguities because every counting rate at this angle showed fluctuation to a certain

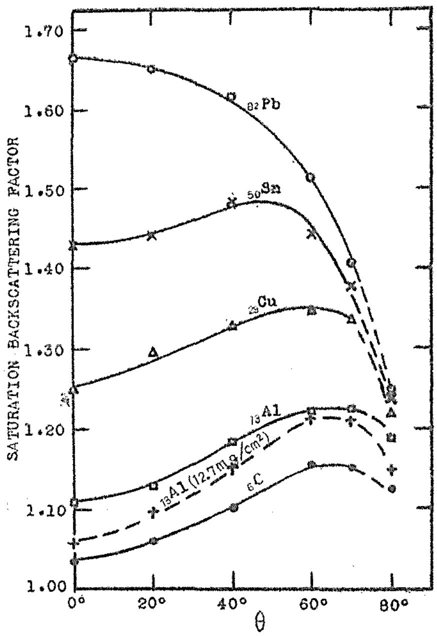

Fig. 10. Angular distribution of the saturation backscattering factor for β-rays of I^{131} with several backings.

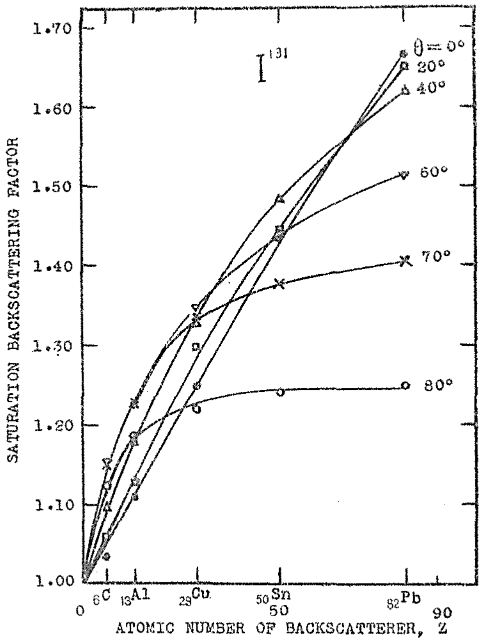

Fig. 11. Saturation backscatting factor for β-rays of I^{131} as a function of atomic number of backscatterer

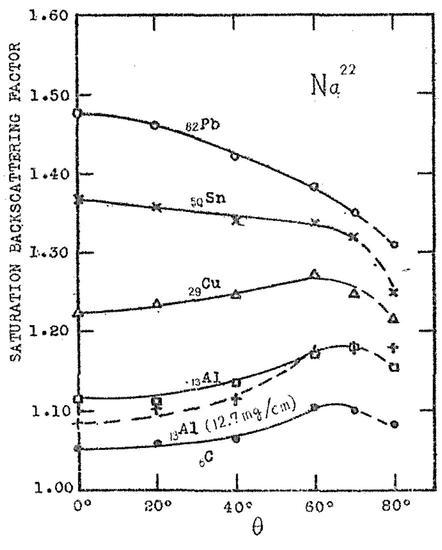

Fig. 12. Angular distribution of the saturation backscattering factor for β^{+}-rays of Na^{22} with several backings.

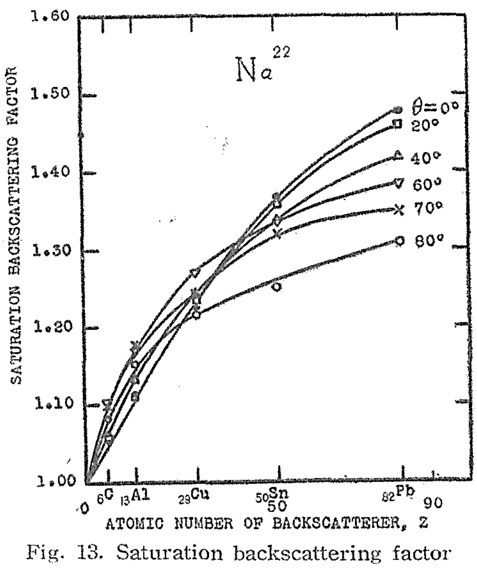

Fig. 13. Saturation backscattering factor for β^{+}-rays of Na^{22} as a function of atomic number of backscatterer.

extent owing to some causes not clearly explained. However, the curve of the angular distribution of the saturation backscattering factor seems to have probably a peak at about $\theta=70°$ when $_6C$, $_{13}Al$, and $_{29}Cu$ are used as backings as shown in Figs. 6, 8, 10, and 12, and from Fig. 6 it can be seen that for Sr^{89} the peak is steeper for thinner aluminium backings. On the other hand, Seliger[11] has observed that the curve is monotonous even for low Z backing materials. From Fig. 7 one can see that backscattering for large θ reaches saturation at thinner backings and the saturation value for large angle is larger than that for smaller angle. This tendency seemes to support the discussion given by Seliger that the side scattering effect is predominant for thin and low Z backing materials. It is also noted that the curves of saturation backscattering factors as functions of Z of backings bend more exceedingly for larger angles, as shown in Figs. 9, 11, and 13.

When the source supporting film attached to a backing is rotated by 180°, the backscatterer then acts an absorber. By this geometry we could measure the forward scattering of the β-rays of Sr^{89}. The angular distribution of the forward

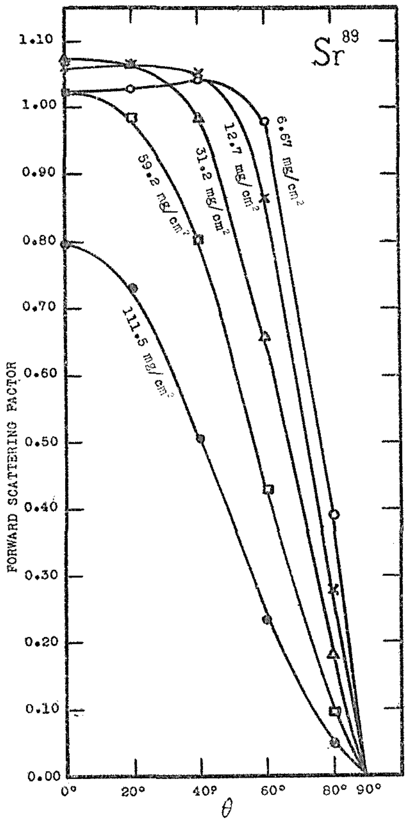

Fig. 14. Angular distribution of the forward scattering factor for β-rays of Sr^{89} with aluminium scatterers.

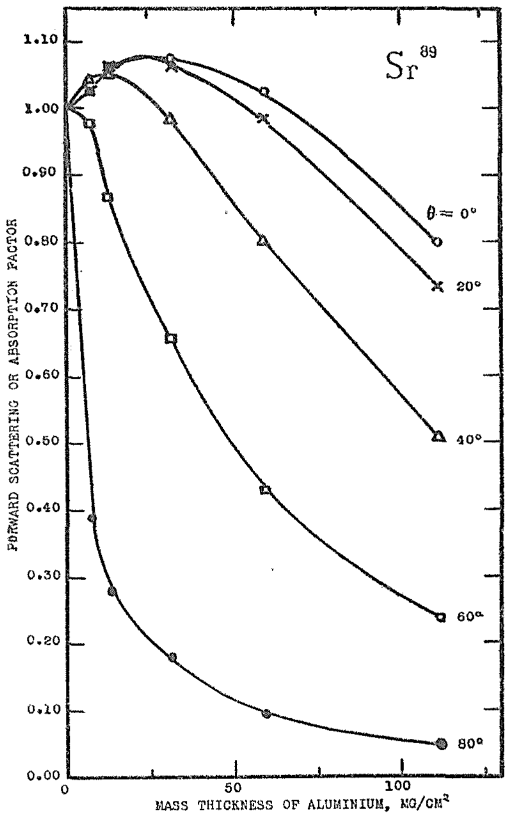

Fig. 15. The forward scattering or absorption for β-rays of Sr^{89} as a function of thickness of the aluminium scatterer.

scattering factor for aluminium scatterers is shown in Fig. 14. From this result it can be seen that when a thin scatterer is used, more β-particles reach the detector than when no scatterer; and an effect of "lens effect" is observed owing to the forward scattering. In Fig. 15 the absorption or forward scattering factor at various angle is given.

All the results obtained by the present experiment naturally depend on the geometrical arrangement of the apparatus, and it seems to be considerably difficult to treat the backscattering of β-rays theoretically owing to the complexity of scattering effects in the matter. However, the data obtained should be very helpful to those working in actual practice in radioactivity measurements, where an end-window G-M tube is often used as a detector. Further investigations on the backscattering effect of the β-rays are now in progress.

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