S 72. *Back-scattering of Electrons into Geiger–Müller Counters.*

By L. YAFFE and K. M. JUSTUS.

The back-scattering of electrons into a Geiger–Müller counter has been studied, and increases in counting rates determined. The effect of varying the energy of the β-emitter, the atomic number, and the mass thickness of the back-scatterer has been determined. Empirical relationships are given from which correction factors may be determined. The characteristics of the scattered radiation are shown. Suggestions are made for standardising counting techniques.

THE problem of accurate routine measurement of β-radiation is one which confronts many laboratories. This paper is concerned with some of the factors which may lead to inaccurate measurement, and deals with the back-scattering into the counter by the sample support and surrounding material.

The reflection and scattering of electrons have been studied by many investigators : as complete a bibliography as could be assembled is given at the end.

Early investigators thought that what we now consider to be scattered radiation was a type of secondary radiation emitted by the material being studied, under the influence of the original β-radiation. This concept gradually vanished, and later investigators became concerned with the analogy to light scattering, studying angles of incidence and reflection. These investigators very rarely recorded sufficient quantitative data regarding the material used as the reflector, or the geometry of the counting system, to allow any practical conclusions to be drawn. After the Rutherford scheme of atomic structure came into general favour, experimenters concerned themselves with the scattering by atomic nuclei and attempted to derive mathematical formulations for the scattering mechanism. A full discussion of this aspect of the work is given by Rutherford, Chadwick, and Ellis (*op. cit.*) and a theory for β-scattering is presented. The essential condition for this theory to hold is that " single " scattering must occur, *i.e.*, the β-particle passing near a nucleus is deflected without the angle of deflection subsequently being changed by other encounters. That is, foils which are used as scatterers must be very thin, and this is a condition which is very rarely realised in practice owing to difficulties of manipulation. As a result, " plural " or even " multiple " scattering occurs and on a theoretical basis the predictions become very difficult.

Work in recent years has taken the form of studying the scattering of electrons by gases and the verification of Mott's calculations (*loc. cit.*). He calculated the scattering of β-particles by an atomic nucleus from the wave-mechanical viewpoint.

From the practical point of view the above work is not exceedingly helpful. In practice, a sample to be measured in a Geiger–Müller counter is placed on a tray of finite thickness which is then put in a position close to the counter. Unquestionably, multiple scattering occurs. If the measurement of the number of β-particles emitted is to be quantitative, and comparisons are to be made between β-emitters with different energy spectra, or even the same β-emitters on different trays, then much more information must exist for correction purposes. Work along these lines has been recently published by Zumwalt (U.S. Atomic Energy Commission, MDDC-1346) and by Cowing and De Amicis (*Science*, 1948, **100**, 187).

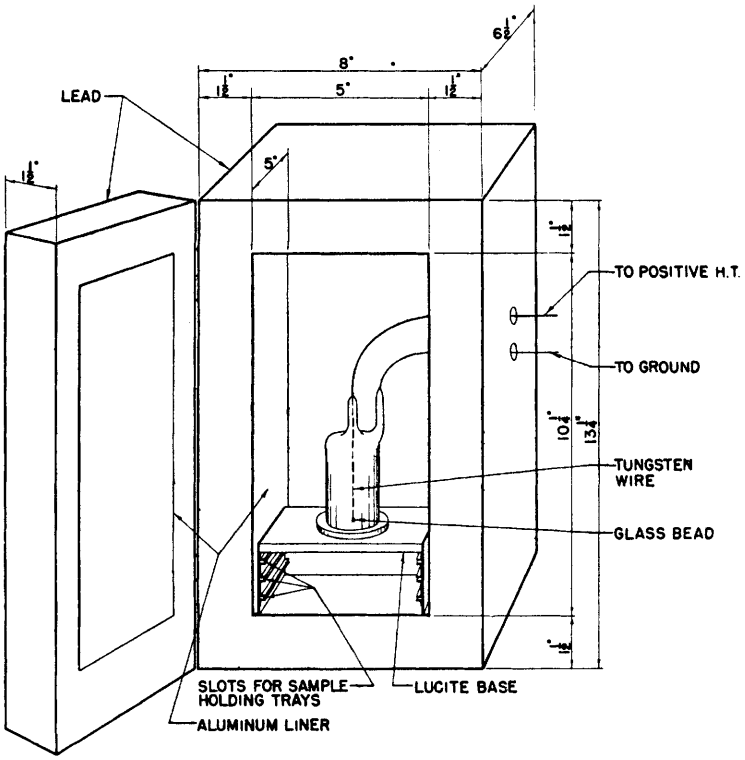
EXPERIMENTAL.

The Geiger–Müller counter used was the " end-window " or " bell-jar " type of counter filled with argon and alcohol at a pressure of 9·5 and 0·5 cm. of Hg, respectively. The window thickness was 2·8 mg./cm.^{2} unless otherwise stated. An isometric projection of the counter and castle arrangement is shown in Fig. 1. The lucite counter base is slotted to allow the sample to be placed in any one of a number of positions, thus varying the geometrical efficiency of the counter by changing the solid angle subtended by it. The entire counter assembly is enclosed in a lead chamber, or " castle " as it is commonly called, with walls 1½" thick to cut out as much stray radiation as possible, thus reducing the background. The background count in such an arrangement varied from 15 to 20 counts per minute. All dimensions may be taken from Fig. 1, and it is hoped that this geometrical system which is already used by many workers may be reproduced by others, and direct use made of the data presented.

All samples, unless otherwise stated, were mounted on very thin films of " Formvar " resin (polyvinyl formal). The technique of preparing these films, although probably not new, is extremely useful and a brief description follows. 10 Mg. of the resin (or other amount depending on the mass thickness of

film required) are dissolved in 5 ml. of ethylene chloride. The solution is spread over 100 cm.^{2} of highly polished plane glass, and the solvent allowed to evaporate. When evaporation is complete, the glass plate is placed in water, the film carefully removed by " teasing " it with the end of a spatula, and the film is floated on the water. The film may then be used to cover a hole on an aluminium tray which fits into the slots in the counter base shown in Fig. 1. The film was then dried under an infra-red lamp. Films used usually had a mass thickness of 100 μg. per cm.^{2} and possessed good tensile strength. By this method it is very easy to prepare consistently good films as thin as 25 μg. per cm.^{2}. These films show good resistance to alkaline or neutral solutions, but are attacked by acid. Polystyrene films prepared by the same technique were found to be acid-resistant and were used when necessary.

FIG. 1.



Showing Geiger–Müller counter in lead castle.

All β-emitters used were of very high specific activity. They were placed on the film in the form of a solution and allowed to evaporate. Usually 0·01 ml. of the solution was used, and after evaporation the mass remaining was less than 1 μg. per cm.^{2}. The sample approximated a point source.

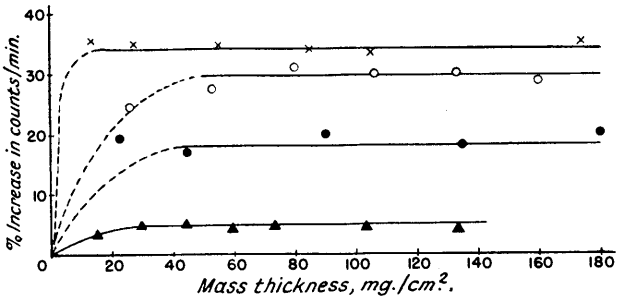
Backing materials used were the purest metals available and were cemented in position as closely as possible behind the sample. All measurements, unless otherwise stated, were made with the sample on the top shelf of the counter base, as shown in Fig. 1.

The β-emitters used had the following characteristics :

	Half-life.	Maximum energy of β^-, Mev.
^{14}C	6400 years	0·154
^{35}S	87·1 days	0·169
^{60}Co	5·3 years	0·30
^{131}I	8·0 days	0·61
^{32}P	14·3 days	1·70
^{106}Ru–^{106}Rh	1·0 year–30 sec.	Ru, 0·03 Rh, 2·8 (20%), 3·9 (80%)

Results.—In Figs. 2—6 inclusive are shown the variation of the percentage increase in back-scattering with increasing mass thickness of back-scatterer for ^{35}S, ^{60}Co, ^{131}I, ^{32}P, and ^{106}Rh, aluminium, copper, silver, and lead being used as back-scatterer. Zero increase in back-scattering is taken as the count registered with no backing save the thin film, air, and the contribution introduced by the lead castle. The results show that in each case as the mass thickness increases the count recorded will increase until a saturation value is reached which we term " saturation back-scattering." The mass required for saturation back-scattering is independent of Z, but the value of the increase due to back-scattering is a critical function of Z.

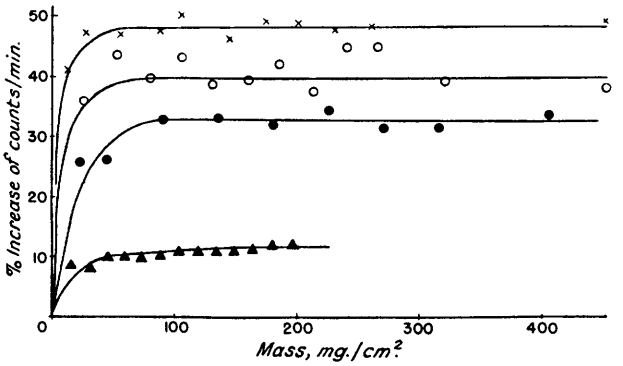
FIG. 2.



Back-scattering for ^{35}S *with various thicknesses of*

Lead ×. *Copper* •.
Silver ○. *Aluminium* ▲.

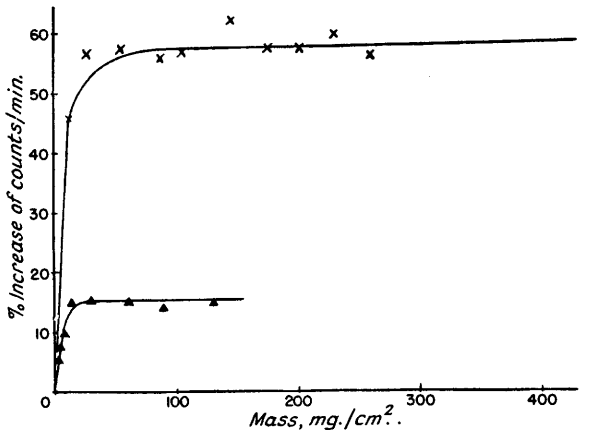
FIG. 3.



Back-scattering for ^{60}Co *with various thicknesses of*

Lead ×. *Copper* •.
Silver ○. *Aluminium* ▲.

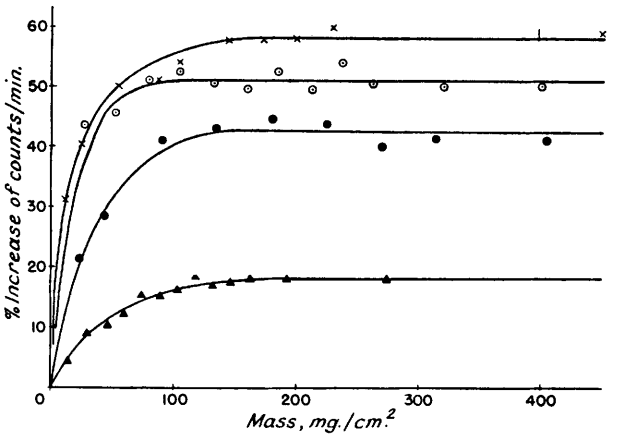
FIG. 4.



Back-scattering for ^{131}I *with various thicknesses of*

Lead ×. *Aluminium* ▲.

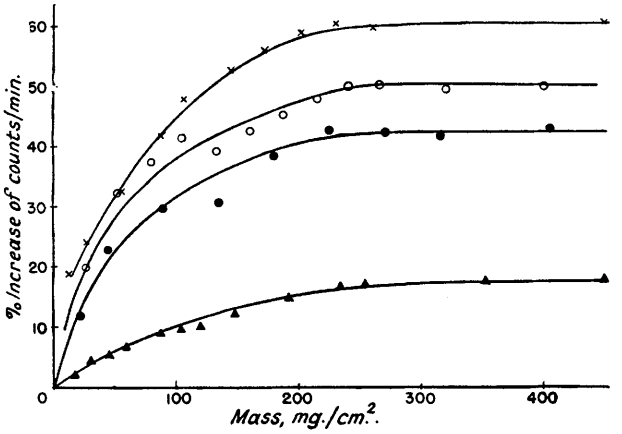
FIG. 5.



Back-scattering for ^{32}P *with various thicknesses of*

Lead ×. *Copper* •.
Silver ⊙. *Aluminium* ▲.

FIG. 6.



Back-scattering for ^{106}Rh *with various thicknesses of*

Lead ×. *Copper* •.
Silver ○. *Aluminium* ▲.

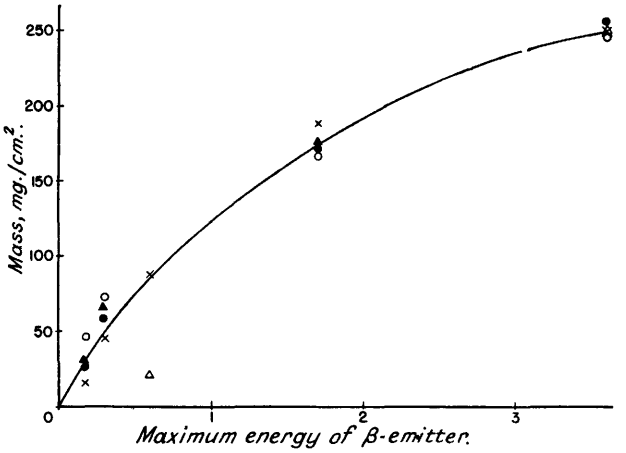
In Fig. 7 is shown the relation between the mass needed for " saturation " back-scattering and the maximum energy of the β-emitter. Fig. 8 gives the relationship between the range of the β-emitter in aluminium and the mass needed for saturation back-scattering, using the range–energy curve quoted by Glendenin (*Nucleonics*, 1948, **2**, 1, 12).

From Figs. 2—6 it can be seen that the number of counts recorded by a counter from the same sample will vary considerably with the mass thickness of the back-scatterer, or tray. Since the increase is very rapid in the initial portion of the curves, it is obvious that the practice employed in many laboratories of measuring samples on thin plates to minimise back-scattering has its dangers owing to the fact that usually this means that the tray thickness corresponds to the steeply ascending part of the curve. Trays cut from the same sheet of metal may not give reproducible results owing to variations in the thickness of the sheet. Two experimental techniques are possible. Either the mass thickness–back-scattering curves are determined, or all counting is done with sufficient backing so that saturation back-scattering is taking place.

As a rough guide, the following empirical relationships obtained from Figs. 7 and 8 may be used to determine the mass required for saturation back-scattering : $M^2 = 36R$, where R = range in mg./cm.^{2}, and M = mass in mg./cm.^{2} needed for saturation back-scattering; $M = 116E^{2/3}$, where E = maximum energy of the β-emitter in Mev., up to 3 Mev.

In Fig. 9 is shown the variation in saturation back-scattering with the atomic number of the back-scatterer for the various β-emitters measured. The curves extrapolate to a "negative" value for the percentage of saturation back-scattering at zero atomic number. This is due to the arbitrary definition of zero percentage increase due to back-scattering as that count obtained with the sample on a thin film in the standard position when actually some scattering occurs from the castle walls and the mount. Using this extrapolated value to get the true count, and knowing the solid angle subtended by the counter, we may determine the absolute β-disintegration rate.

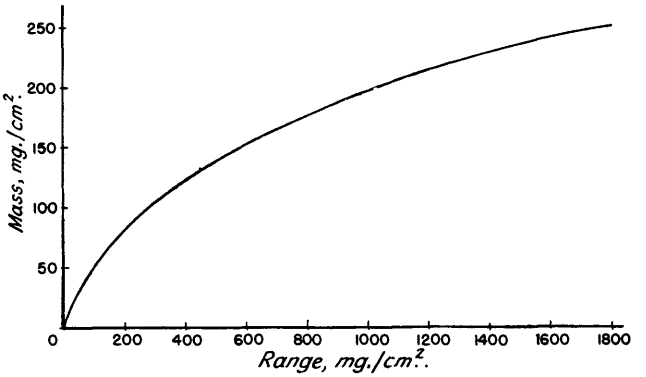
FIG. 7.



Relation between maximum energy (MeV.) of a β-emitter and the mass required for saturation back-scattering for

Lead ×. *Copper* •.
Silver ○. *Aluminium* ▲.

FIG. 8.



Relation between range of β-emitter and mass needed for saturation back-scattering.

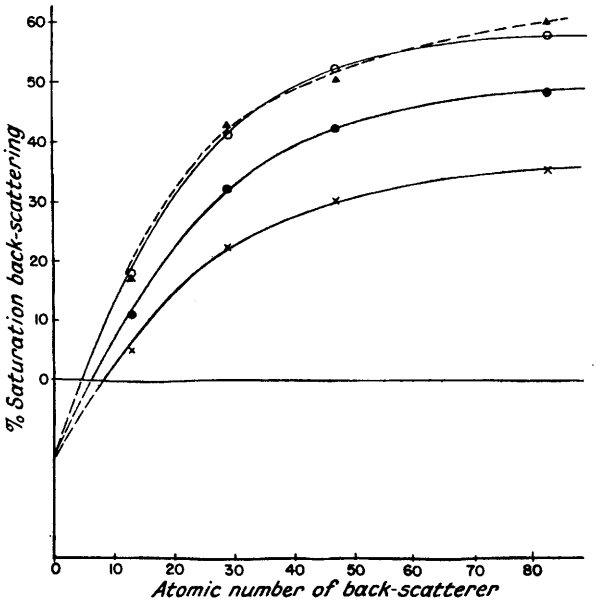
The fact that this scattering is contributed by the castle has also been verified experimentally. The counting base was mounted from the ceiling in the middle of a room so that only scattering from the air was a contributing factor. The results agreed with those shown in Fig. 9. This back-scattering from the castle is reduced from about 8% to 4% if the castle walls are lined with aluminium.

Fig. 15 shows the maximum increase in counting rate (saturation value) obtained from β-emitters of various energies using various metals as back-scatterers, and if identical geometry is used this may be used as a correction curve. By a combination of the above curves it is possible to predict the amount of material necessary to get saturation back-scattering and to correct for the amount of back-scattering present.

In Fig. 10 is shown the variation in back-scattering with change in atomic number of back-scatterer, a back-scatterer of mass thickness 55 mg./cm.² being used for various β-emitters. Again an apparent negative value results owing to the arbitrary assumption of the zero value. If the atomic number is kept constant, as well as the mass thickness, *i.e.*, if the same back-scatterer is used throughout for all the β-emitters, then the curve shown in Fig. 11 will result. The results for two cases, $Z = 47$ and $Z = 82$, silver and lead, respectively, are shown. The curves rise very steeply, show a maximum at 1 Mev. and gradually fall. This result has already been briefly reported by us (*Physical Rev.*, 1948,

73, 1400). Since the curve rises so steeply in the initial portion, it can be seen that in this region the back-scattering is a very sensitive function of the maximum energy of the β-emitter. In this manner the maximum energy of ^{35}S was shown to be 0·165 ± 0·005 Mev. rather than 0·107—0·120 as had been previously determined (Libby, *Anal. Chem.*, 1947, **19**, 2). This has been confirmed by Solomon *et al.* (*Physical Rev.*, 1947, **72**, 1097) and by ourselves (*Canadian J. Res.*, 1948, *B*, **26**, 734) by absorption methods, and by Cook *et al.* (*Physical Rev.*, 1948, **74**, 548) using a β-spectrometer. This method provides a very rapid means of determining the maximum energy of β-emitters with simple spectra. Once the empirical curve has been obtained for a given geometrical set-up then, with only two measurements, one with, and the other without a back-scatterer, the maximum energy may be determined. In some cases an alternative value will be obtained, but this ambiguity can be resolved very easily by one additional measurement with an absorber.

FIG. 9.



Saturation back-scattering obtained for various β-emitters with metals of increasing atomic number.

^{35}S ×. ^{60}Co •.
^{32}P ○. ^{106}Rh ▲.

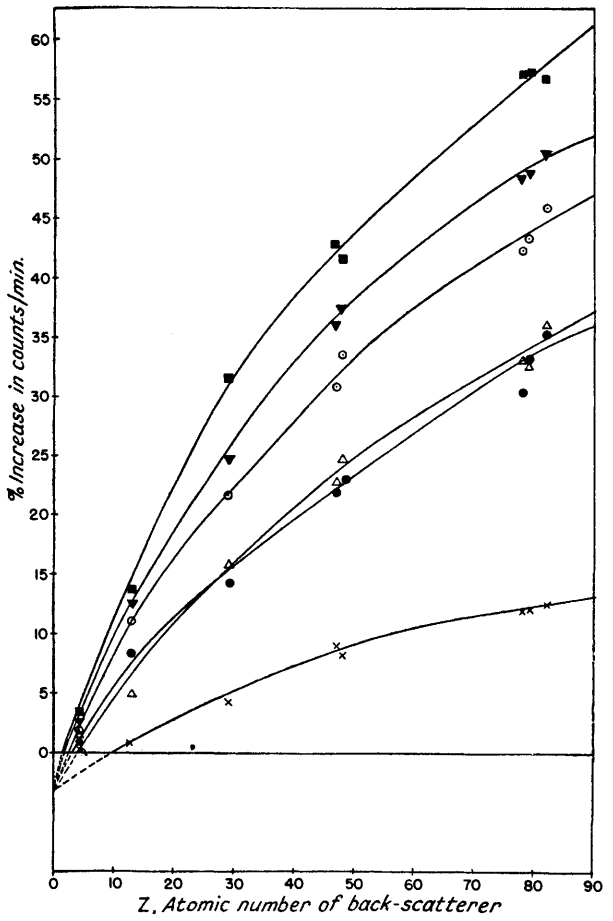
An attempt was made to explain the shape of the curve obtained. In Fig. 12 are shown the curves obtained with counters of two different window thicknesses, 4·5 mg./cm.^{2} and 15 mg./cm.^{2}. These curves are not strictly comparable with the curve shown in Fig. 11 where the counter-window is 2·8 mg./cm.^{2}, since different counters were used. It may be seen, however, that the shape of the curve is essentially the same and that it is very doubtful if the rapid falling off of the curve is due to window absorption. As yet, no plausible explanation, backed by experimental results, has been found which will account for this.

In Fig. 13 is shown the effect on this curve of varying the mass thickness of the back-scatterer. The curve approaches a maximum value as before, but as the mass thickness is increased, a constant value is reached. It would appear that as the mass of the back-scatterer is increased the volume of material offered to the electrons is at first insufficient to provide complete reflection to the electrons. As the mass is increased a maximum occurs for electrons of energy of about 1 Mev. As the energy increases, the mass is again insufficient to provide total reflection, some of the electrons passing through the metal. As the volume presented to the electrons increases, the curve flattens and a maximum is reached.

In Fig. 14 is shown the effect of keeping the thickness of a tray constant (0·020″) and varying the atomic number. The count of a sample of, *e.g.*, ^{106}Rh, may be increased in this manner by about 75%.

The angular distribution of the back-scattered radiation has been determined by using a specially constructed apparatus. This hung in the centre of the room suspended from the ceiling. The β-emitter was an essentially weightless, point source of ^{32}P mounted on a "Formvar" film. The source was maintained at a constant distance from the counter-window and on the axis of the counter. The source support could be rotated so that it intersected the axis of the counter at various angles. Normally the back-scattering contribution was then due only to the air since the counter did not "see" any other material. A piece of lead could be placed behind the source and rotated with it. When rotated through 180° the back-scatterer now acted as an absorber. In this manner the angular distribution of the β-radiation with no back-scatterer, with back-scatterer, and with absorber could be obtained. The results are shown in Fig. 18.

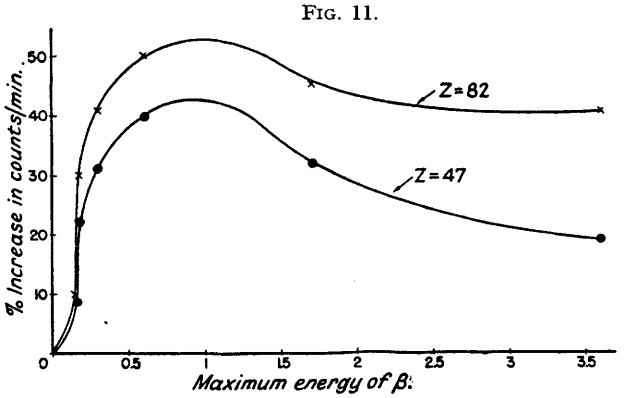
FIG. 10.



Variation in back-scattering with change in atomic number of back-scatterer using constant mass thickness of back-scatterer (55 mg./cm.²).

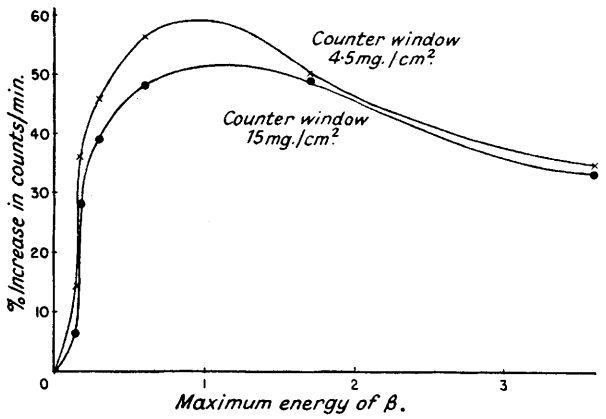
^{131}I	■.	^{35}S	△.
^{32}P	▼.	^{106}Rh	●.
^{60}Co	⊙.	^{14}C	×.

FIG. 11.



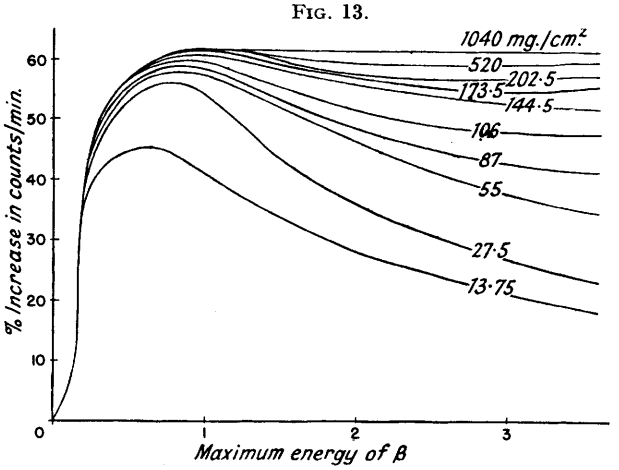
Variation of the percentage increase in the number of counts per minute due to back-scattering with the maximum energy (Mev.) of the β-emitter. Mass thickness of back-scatterer, 55 mg./cm.².

FIG. 12.



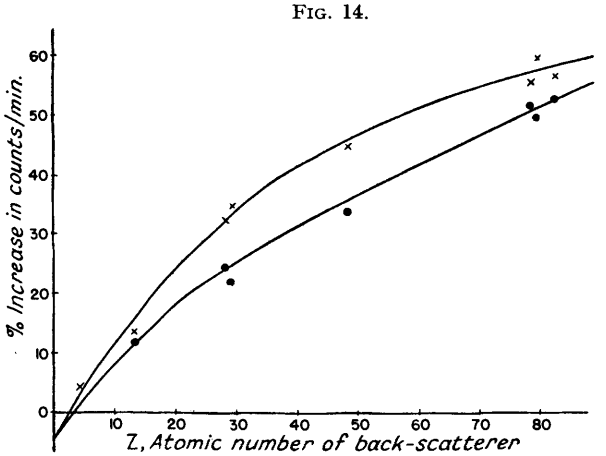
Variation of percentage increase in number of counts due to back-scattering by material of atomic number 82 *and constant mass thickness with maximum energy (MeV.) of β-emitter. Mass thickness* $=55$ *mg./cm.*^{2} *for various counter-window thicknesses.*

FIG. 13.



Variation in the percentage increase in number of counts due to back-scattering by material of atomic number 82 *and various mass thicknesses with maximum energy of β-emitter (MeV.).*

FIG. 14.



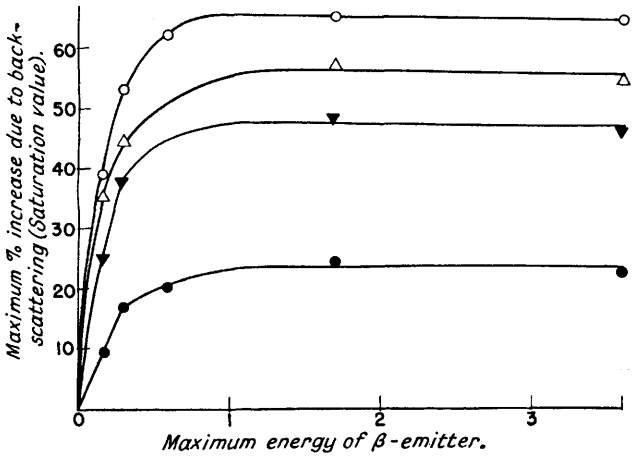
Variation of percentage increase in counts per minute with change in atomic number of tray. Thickness of tray kept constant (0·020″).

^{106}Rh ×. ^{60}Co •.

It can readily be seen that neither the absorber radiation nor the back-scattered radiation is isotropic. A maximum occurs in a plane normal to the source. By inspection of the results obtained with the 26·3 mg./cm.^{2} lead plate it can also be seen that an anomalously large number of electrons are back-scattered into the counter. This may possibly be due to two effects, a geometrical one or electron multiplication.

Absorption curves for ^{35}S and ^{106}Rh with and without back-scatterer are shown in Figs. 16 and 17. It can be seen that some degradation of the β-radiation does occur, but that no very soft component exists, such as might be expected if electron multiplication were occurring owing to bombardment of the metal.

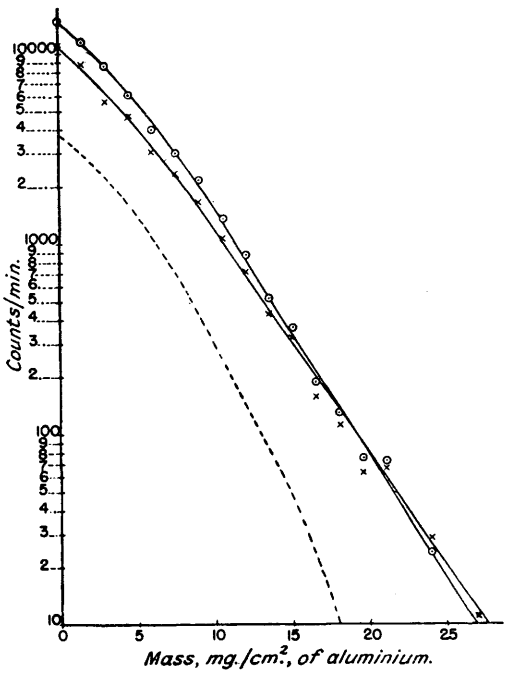
FIG. 15.



Maximum increase due to back-scattering for β-emitters of various energies.

○ Pb. ▼ Cu.
△ Ag. ● Al.

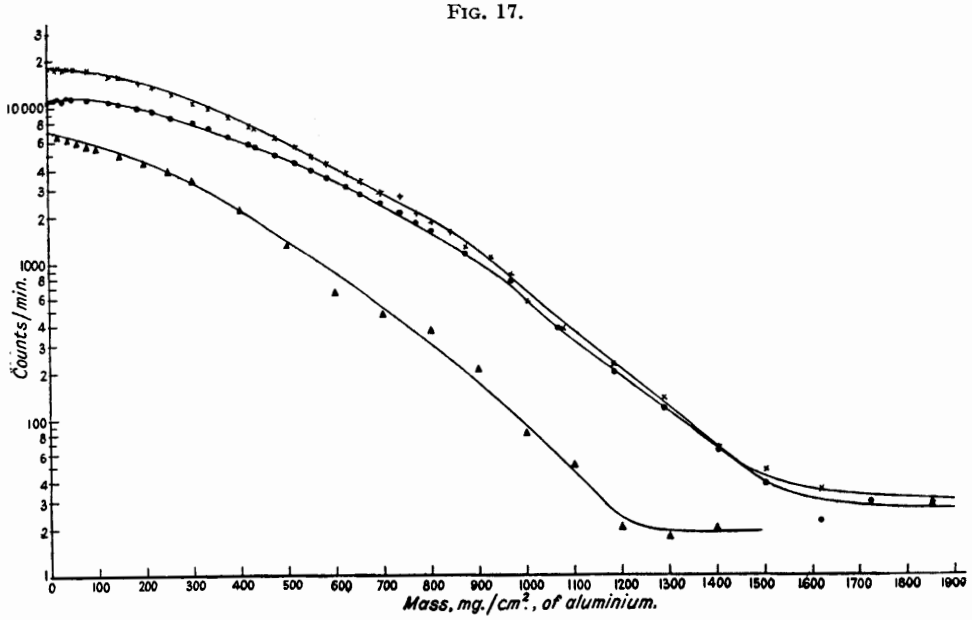
FIG. 16.



^{35}S *absorption curve.*

—×—×— *Without lead backing.*
—⊙—⊙— *With lead backing* 1040 *mg./cm.*^{2}.
- - - - - - - - - *Secondary rays.*

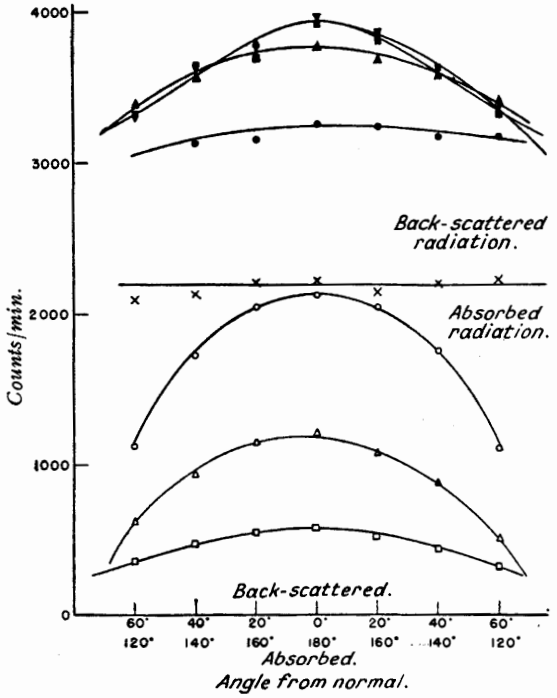
FIG. 17.



^{106}Rh *absorption curve.*

●——● *Without lead backing.*
×——× *With lead backing* 1040 *mg./cm.²*.
▲——▲ *Reflected radiation.*

FIG. 18.



Angular distribution of β-rays.

× *No back-scatterer.*
○ 26·3 *mg./cm.²* Pb *absorber.*
△ 88 *mg./cm.²* Pb *absorber.*
□ 150 *mg./cm.²* Pb *absorber.*
● 26·3 *mg./cm.²* Pb *back-scatterer.*
▲ 88 *mg./cm.²* Pb *back-scatterer.*
■ 150 *mg./cm.²* Pb *back-scatterer.*
▼ 440 *mg./cm.²* Pb *back-scatterer.*

It is also very difficult to ascribe the large increase to a geometrical effect, and investigations to elucidate this are continuing, magnetic deflection methods being used to determine the type of radiation being measured.

All the above data have been obtained with the sample deposited on a thin film and the metals which were used as back-scatterers placed as closely as possible behind the film. Although the above correction factors may be used to correct for back-scattering in cases where metals like aluminium or silver have been used as trays, yet it should be pointed out that, with certain metals like lead, if the sample is deposited directly on the metal, a greater increase due to back-scattering is observed. This appears to be some sort of surface effect, due to the malleable nature of the metal, and is being investigated further.

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