DET KGL. DANSKE VIDENSKABERNES SELSKAB
MATEMATISK-FYSISKE MEDDELELSER, BIND XX, NR. 6

# THE BEGINNING OF THE PHOTON-INITIATED ROSSI-CURVE FOR Pb, Fe and Al

BY

B. TRUMPY

KØBENHAVN
I KOMMISSION HOS EJNAR MUNKSGAARD
1943

Printed in Denmark.
Bianco Lunos Bogtrykkeri A/S.

## 1. Introduction.

The beginning of the Rossi-Curve has in recent years been the object of extensive examination by a long series of investigators. Thus Hu Chien Shan, Kisilbasch, Ketiladge [1] [2], Watase [3] and Clay and Jonker [4] have by means of Geiger-Müller counters examined the shower-production in thin sheets of several different materials. The prevailing view among these investigators seems to be that the usual experimental arrangement with three or more counter tubes in coincidence gives a Rossi-Curve, the course of which—at least for small thicknesses—is essentially determined by the soft component of the radiation complex.

The thickness of the shower-producing material was accordingly indicated in shower-units—$l$—, and it was then found—with essential agreement among the authors—that the Rossi-Curves for the different materials were completely indentical within the limits $l = 0$ to $l = 1$. Clay and Jonker [4] consider this result a confirmation of the cascade-theory of electron-showers.

To this, however, must be remarked that a theoretical calculation—based upon the cascade-theory—of the number of showers produced by the soft radiation component, leads to results actually contradicting the experiments mentioned above. Calculations to this effect are made by Arley and Eriksen [5] [6]. They have calculated the theoretical Rossi-Curve for different shower-producing materials, both for a primary radiation consisting of electrons only and of photons only. By combining these results the Rossi-Curves for the soft component are determined as a whole, and the results may to a large extent be directly applied to experiments with counter tubes. The authors find that the Rossi-Curves for small thicknesses *do not coincide* for different materials—the curve within the limits $0 < l < 1$ lying the higher, the greater the atom number of the material. In a paper previously published on the shower production of mesons we[7] have pointed out, as already pointed out by ARLEY[5][6], that this disagreement between theory and experiment is probably due to the fact that the experiments also include the hard component. By the usual determination of the Rossi-Curve—by means of counter tubes—those showers which are produced by the hard component will also be measured. Our experiments with a Wilson-Chamber[7] have shown that the equilibrium between the mesons and their secondaries is reached in very thin metal sheets, and the influence of the meson showers on the course of the beginning of the usual Rossi-Curve is, therefore, not to be ignored. Our experiments showed, further, that the curves giving the number of meson secondaries as a function of the sheet thickness for different materials very nearly coincide, if the thickness is stated in g/cm$^2$. This fact shows that the Rossi-Curves of the hard component do not coincide if the thickness is stated in shower units—l—, lying in this case the lower, the greater the atom number of the material.

As the Rossi-Curves plotted on an l-scale for the whole radiation according to the above experiments coincide for small thicknesses of different materials we may, further, draw the conclusion that this can not be the case for *the soft radiation alone*, the curves lying in this case necessarily higher, the greater the atom number of the material.

This fact is qualitatively in accordance with the theory.

In order to find a base for a quantitative verification of the cascade theory on this point we have, by means of the method of anti-coincidences, made an experimental determination of the photon-initiated Rossi-Curve for thin sheets of different materials. In the following we shall give a summary of the preliminary results of this investigation made with Pb, Fe and Al, and compare them with the theoretical calculations of ARLEY and ERIKSEN.

## 2. Experimental Arrangement.

Fig. 1 gives a vertical cut through the experimental arrangement perpendicular to the axis of the counter tubes. The combination $K_1$, $K_2$ and $K_3$ consists of counter tubes with a diameter of 2 cm and an effective length of 15 cm. The three tubes $K_3$ are in parallel. $K_1$, $K_2$ and $K_3$ are placed in an ordinary coincidence coupling, and this part of the apparatus has, according to performed measurements, a resolving power of $3.10^{-6}$ min.

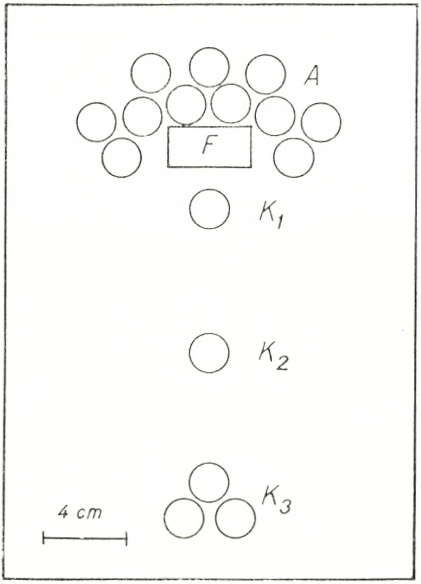

Fig. 1. Arrangement of counter tubes.

Above the counter tubes K are placed in parallel a total of 11 counter tubes, A, each with a length of 35 cm. These counters are coupled in anti-coincidence, i. e.: a coincidence in the K tubes will only be registered provided that no simultaneous discharge is taking place in one or more of the tubes A. In the space between the tubes A and K sheets F of different materials and varying thickness may be placed.

What is measured with this arrangement is thus, obviously, the showers—containing at least one electron—which are produced in the metal sheet F by a non-ionising radiation. In a previously published paper[8)] we have shown that in the cosmic radiation complex there do not exist neutral mesons which produce ionising radiation in traceable quantities in metal sheets of the thickness applied here. The effect measured by the experimental arrangement in fig. 1 will, therefore, exclusively be due to photons, and what is measured will accordingly be the photon-initiated Rossi-Curve, corresponding to a number of electrons per shower of $N \geq 1$. As the zero-effect by measurements with thin metal sheets may have a considerable influence on the result, the attempt has been made to reduce the former as much as possible by completely covering the sheet F with tubes in anti-coincidence. The remaining zero-effect, 4.8—which is relatively insignificant—is then chiefly due to a production of showers by photons in the lower walls of the tubes A. This wall is made of brass, 0.4 mm thick.

The resolving power of the anti-coincidence coupling was determined by placing the tubes A besides the tubes K at a distance of about 1 m. from the latter. Between A and K there was placed a lead filter with a thickness of 10 cm. The number of coincidences $N_1$ in the K tubes was measured while the A-tubes were excluded and next the number of anti-coincidences —$N_2$— was counted.

$N = N_1 - N_2$ then gives the number of accidental coincidences between the combinations A and K, and the resolving power may be calculated in the usual way. It was with 11 A-tubes about $10^{-5}$ min.

## 3. Results.

Measurements were made with Pb, Fe and Al. Maximum of thickness used for the sheet F was in the first experiments the same for all materials, restricted by the geometry of the experimental arrangement, and it is therefore—expressed in l-units—decreasing from Pb to Al.

In the tables 1, 2 and 3 we give the results of the measurements, the zero-effect having been subtracted.

Table 1.
Pb.

| Thickness in l-units | Hours | Anti-coincidences per Hour |
|---|---|---|
| 0.28 | 142.5 | 8.5 + 0.3 |
| 0.56 | 164.0 | 14.5 + 0.3 |
| 0.84 | 167.0 | 18.5 + 0.4 |
| 1.12 | 165.0 | 20.5 + 0.5 |
| 1.84 | 294.0 | 23.3 + 0.6 |
| 2.93 | 145.0 | 21.0 + 0.4 |
| 3.69 | 74.0 | 19.0 + 0.6 |
| 4.80 | 120.0 | 16.6 + 0.4 |
| 6.39 | 22.0 | 10.9 + 0.9 |

The last measurement in Table 3 is made with about 73 mm Al. In this case the upper counter tubes—A—had to be raised in order to make room for the thick aluminium sheet. This circumstance means that the geometry of the experimental arrangement was somewhat changed, and it is possible that we have, consequently, to allow for a greater margin of error in this measurement than for the other measurements, the correction

Table 2.
Fe.

| Thickness in l-units | Hours | Anti-coincidences per Hour |
|---|---|---|
| 0.25 | 69.0 | 8.2 + 0.5 |
| 0.50 | 77.0 | 11.1 + 0.5 |
| 0.75 | 72.0 | 14.5 + 0.5 |
| 1.00 | 167.8 | 15.7 + 0.4 |
| 1.50 | 183.3 | 17.5 + 0.4 |
| 2.43 | 167.5 | 15.7 + 0.4 |

for the zero-effect being among other things greater. In fig. 2 the results in the tables 1—3 are shown in curves, the fully drawn

Table 3.
Al.

| Thickness in l-units | Hours | Anti-coincidences per Hour |
|---|---|---|
| 0.09 | 124.0 | 3.3 + 0.3 |
| 0.27 | 120.0 | 7.9 + 0.3 |
| 0.45 | 116.5 | 10.0 + 0.4 |
| 1.10 | 258.8 | 13.8 + 0.2[1] |

[1] Carried out with the tubes A raised.

curves being marked Pb, Fe and Al. As to the broken curves with the same notations see next paragraph.

## 4. Discussion.

Our experiments with the anti-coincidence method give according to fig. 2 the following chief results for $N \geq 1$, N being the number of electrons per shower.

1. The photon-initiated Rossi-Curves for different materials *do not coincide* for small sheet-thicknesses when the latter are plotted in shower units, the curves lying within the limits

$0 < l < 1$ the higher, the greater the atom number of the shower-producing material.

2. The number of anti-coincidences at the maximum of the curve increases with increasing atom number of the shower-producing material and is for Pb 1.7, for Fe 1.3 times greater than for Al.

3. The maximum of the photon-initiated Rossi-Curve advances with increasing atom number of the shower producing material towards greater values of l. Thus it lies for Pb, Fe and Al by the values $l = 2.0$, 1.7 and about 1.1 respectively.

Point 1 stands in direct conflict with the conclusion drawn by Hu, Kisilbasch, Ketiladge, Watase and Clay based on their experiments of the course of the Rossi-Curve by means of the usual coincidence arrangement. This confirms our previously[7)] advanced hypothesis that the hard component in the cosmic radiation has a perceptible influence on the course of the Rossi-Curve, even for very thin sheet of the absorbing material.

It is of great interest to compare our results with the cascade theory for the soft radiation which through Arley has developed so far as to allow for a direct comparison. In their last work Arley and Eriksen have made a theoretical calculation of the course of the photon-initiated Rossi-Curve for different materials. These calculations must, of course, chiefly be founded on our knowledge of the energy spectrum of the photon radiation at the surface of the earth and as experiments cannot as yet give exact information on this subject, the authors have tried to make a calculation of the spectral distribution based on certain simplified assumptions. They suppose e.g. that all electrons and photons found at sea-level are produced by multiplication in the atmosphere of the primary radiation reaching the earth from outside. They further suppose that the primary radiation chiefly consists of high energy electrons, with a spectrum:

$$f(E_0)\,dE_0 = \text{const.}\,\frac{dE_0}{E_0^{1+\gamma}}$$

where the numerical value of $\gamma$ lies between 1 and 2.

These assumptions are not in full accordance with the results of the investigations made in recent years on the transformation

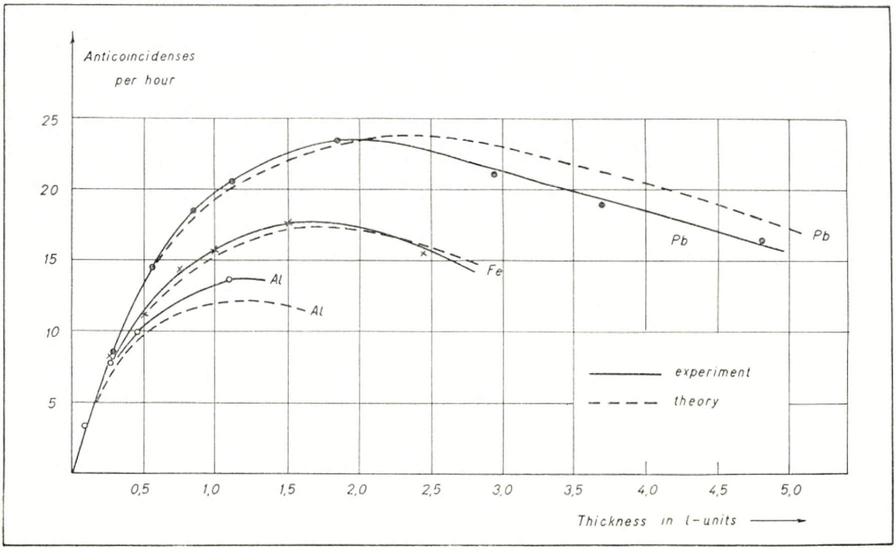


Fig. 2. Photon-initiated Rossi-Curves for Pb, Fe and Al.

of the cosmic radiation complex from the top of the atmosphere to the surface of the earth. It seems especially open to criticism that the photons produced in the atmosphere by multiplication of the electron secondaries of the mesons are not taken into consideration.

We may, however, from numerical calculations confirm the statement of Arley and Eriksen that the ultimate result does not depend significantly upon the form of the spectrum, and the calculated Rossi-Curves may, therefore, be expected to be correct in the main features, even if too much importance must not be attached to a quantitative comparison with the experimental results.

Arley and Eriksen have calculated the photon-initiated Rossi-Curves for Pb, Fe and Al. In these calculations are, however, included both "fast" and "slow" electrons, whereas our counter tube experiments will exclude electrons not being able to penetrate through the tube walls. The limit lies here presumably about $10^7$ e. V., and the "slow" electrons ought accordingly not to be included in the calculations.

We have made some numerical calculations in order to fix the influence on the result when the slow electrons are excluded. The alteration thereby made in the course of the curves is of essential importance only for sheet thicknesses greater than $l = 1.0$, and within the limits which are experimentally examined in this paper it will have a perceptible influence only for the Pb curve. This curve for "fast" electrons is calculated by ARLEY and ERIKSEN (l. c.). The broken curves in fig. 2 represent the theoretical values for Pb, Fe and Al in the case of $N \geq 1$. The theoretical curve for Fe is placed in such a manner that the maximum of the experimental and of the theoretical curve lie on the same level.

As will be seen, the theory renders the chief results in point 1—3 quite correctly. The curves do not coincide within the limits $0 < l < 1$, lying higher, the higher the atom number of the material; the maximum shower number increases with the atom number, and the maximum at the same time advances towards greater values of l. One dare say that also the quantitative accordance between theory and experiment is so good as may be expected, when the approximations used in the calculations are taken into account.

Finally we have to express our sincere thanks to Mr. T. BJORDAL who has rendered valuable aid during the experiments. We shall further express our thanks to The Scientific Research Fund of the Norwegian State (Statens Vitenskapelig Forsknings-fond) which has financed the work.

*Geofysisk Institutt*
*Bergen July 1942.*

## References.


1) Hu Chien Shan: Proc. Roy. Soc. A. **158**, 581, 1937.
2) Hu Chien Shan, Kisilbasch and Ketiladge: Proc. Roy. Soc. A. **161**, 95, 1937.
3) Watase: Proc. Phys. Math. Soc. Japan. **19**, 749, 1937.
4) J. Clay and K. H. Jonker: Physica **VII** 921, 1940.
5) N. Arley: Proc. Roy. Soc. A. **168**, 519, 1938.
6) N. Arley and B. Eriksen: D. Kgl. Danske Vidensk. Selskab, Mat.-fys. Medd. **XVII** 11, 1940.
7) B. Trumpy: Det Kgl. Norske Vid. Sel. Forh. **XIV** 63, 1941.
8) B. Trumpy and T. Bjordal: Bergens Museums Årbok 1942.



Indleveret til Selskabet den 12. Oktober 1942.
Færdig fra Trykkeriet den 18. Januar 1943.