The Rossi Transition Curve for Small Angle Showers*

W. M. NIELSEN, J. E. MORGAN, *Duke University, Durham, North Carolina*

AND

K. Z. MORGAN, *Lenoir Rhyne College, Hickory, North Carolina*

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Measurements have been made of 7° and 28° cosmic-ray shower production in iron up to thicknesses of approximately 320 g/cm². A comparison of the data here presented and measurements previously reported for 38° showers leads to the conclusion that there is no significant difference in the ratio of counting rates at the first maximum of the Rossi transition curve to that under 200 g/cm² for either large or small angle showers. It is concluded that the processes which are responsible for the character of the transition curve under large thicknesses of material are not necessarily restricted to small angles.

1. INTRODUCTION

EVER since the early investigation of Rossi[1] the production of cosmic-ray showers in various materials has been the subject of numerous investigations.[2] These studies have involved the use of G-M counters in various geometrical arrangements and, in general, are in very good agreement as to most of the important features of the transition curve. The well-known first maximum of the transition curve is qualitatively in agreement with what one would expect on the view that such showers are the result of multiplication processes associated with ordinary electrons and quanta. Current theories as to the properties of such particles are unable, however, to account for showers under large layers of material. We have expressed the view based on G-M counter[3] and cloud-chamber[4] studies that a considerable number of such showers, particularly the small ones, are produced by light particles which must be secondary to the penetrating component of the cosmic radiation.

Quite recently Bothe and Schmeiser[5] in a series of interesting papers have presented evidence which they have interpreted as showing that the prominence of the so-called second maximum of such transition curves is a marked function of the angular spread of the detected showers, being more prominent for small angle showers. The significance of these observations has already attracted a good deal of theoretical interest[6] because of their possible relation to the generation of a considerable number of penetrating particles (mesotrons) under large layers of materials. Because of this fact and because of the very direct relation of this work to our investigations referred to above, we have made measurements of small angle (7°) and large angle (28°) showers under layers of iron up to a thickness of approximately 320 g/cm².

2. EXPERIMENTAL ARRANGEMENT AND RESULTS

In the present series of measurements, the experimental techniques are essentially the same as those used in previously reported work with G-M counters from this laboratory. The arrangement of counters is shown in the insert of Fig. 1, which has been drawn to scale. Fourfold coincidences between the inner group of counters and between the outer four counters were counted as 7° and 28° showers, respectively.*

It is well known that this counter arrangement increases the importance of the material com-

* A report on this work was presented at the New York meeting of the American Physical Society, February, 1939.

[1] B. Rossi, Zeits. f. Physik **82**, 151 (1933).

[2] See, for example, such summaries as H. Geiger, Ergebn. d. Exakt. Naturwiss. **14**, 42 (1935); Darol K. Froman and J. C. Stearns, Rev. Mod. Phys. **10**, 133 (1938).

[3] K. Z. Morgan and W. M. Nielsen, Phys. Rev. **52**, 564 (1937); W. M. Nielsen, J. Frank. Inst. **226**, 601 (1938).

[4] J. I. Hopkins, W. M. Nielsen and L. W. Nordheim, Phys. Rev. **55**, 233 (A) (1939).

[5] K. Schmeiser, Naturwiss. **25**, 173 (1937); K. Schemiser and W. Bothe, Naturwiss. **25**, 669–670 (1937); K. Schmeiser and W. Bothe, Ann. d. Physik **32**, 161 (1938).

[6] W. Heitler, Proc. Roy. Soc. **A166**, 529 (1938); W. Heisenberg and H. Euler, Ergebn. d. Exakt. Naturwiss. **17**, 1–69 (1938); G. Wentzel, Phys. Rev. **54**, 869 (1938).

* We are using the terms 7° and 28° showers in the sense heretofore given them in the cosmic-ray literature. Actually the angles may be greater; the length of the counters was 20 cm.

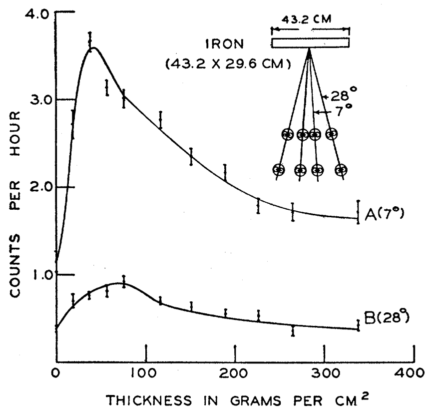

FIG. 1. Fourfold coincidence counting rate of 7° and 28° showers as a function of material thickness in grams per square centimeter. Area of iron plates 43.2×29.6 cm.

pared to the background count as measured by the ratio of the counting rate at the first maximum of the transition curve to the counting rate with no scattering material above the counters.

We have also made similar measurements of 7° and 28° showers generated in layers of iron of twice the cross-sectional area shown in Fig. 1. We felt this was necessary in order to remove the major portion of the background due to showers coming in at appreciable angles with the vertical. The data under these conditions are shown in Fig. 2.

There are considerable differences between the transition curves here presented and those reported by Bothe and Schmeiser, and we shall therefore discuss them in some detail.

DISCUSSION

There has been considerable discussion[5, 7] in the literature as to the existence of a real second maximum in the Rossi transition curve. These investigations have indeed indicated a hump in the curve at a thickness of approximately 200 g/cm² in a considerable number of cases. It is also true that generally the departure from a smooth curve in the region in question is rather small. In the work of Bothe and Schmeiser the shower curves for the smaller angles have been drawn in such a way as to indicate two well-defined peaks. One of us[3] has emphasized that the important conclusion from the work of Bothe and Schmeiser is not that a deviation from a smooth curve seems to be indicated, but rather that there seems to be a progressive increase in the ratio of the counting rate at approximately 200 g/cm² to that at the first maximum, as one goes from the larger to the smaller angle shower curves. The data of Bothe and Schmeiser for the smaller angles show a counting rate at about 200 g/cm² comparable to that at the first maximum. Clearly if the processes which are responsible for the possible second maximum are of such a character as to be largely confined to small angles and are of increasing importance at large thicknesses of material, we should expect just such a change. In our discussion which follows we are only interested in this feature of the curves.

The curves A of Figs. 1 and 2 appear quite normal and are very similar, as discussed later, to earlier measurements in this laboratory and elsewhere. One very difficult question in any discussion of the Rossi transition curve is the treatment of the background. We have tried to remove, insofar as possible, complications of this kind by using a counter arrangement which is most sensitive to twofold showers from above, and have thereby obtained a relatively high ratio between the number of showers produced in sufficiently thick layers of iron to the background count. It is also clear that such an arrangement is more effective in the absorption of the background count than one which detects

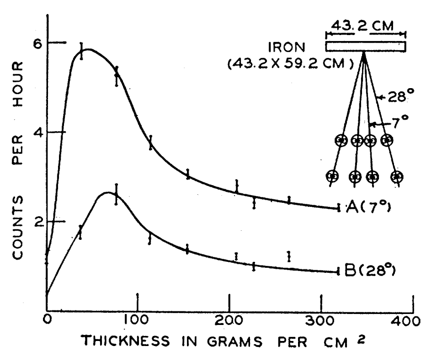

FIG. 2. Fourfold coincidence counting rate of 7° and 28° showers as a function of material thickness in grams per square centimeter. Area of iron plates 43.2×59.2 cm.

[7] J. N. Hummel, Naturwiss. **22**, 170 (1934); H. Kulenkampff, Physik. Zeits. **35**, 996 (1934); H. Maass, Physik. Zeits. **35**, 858 (1934); A. Drigo, Ricerca. Scient. **5**, 88 (1934); M. Ackelmann, Naturwiss. **22**, 169 (1934); J. Clay, A. van Germert and J. T. Wiersma, Physica **7**, 627 (1936).

only two- or threefold coincidences. That very few of the coincidences are due to higher multiple showers from the sides was shown by placing absorbing materials at the sides of the counters in which case the counting rate was sensibly unaltered. We are therefore fairly certain that the measured counting rates give a qualitative indication of the effects caused by the presence of the iron above the counters. Curves *A* and *B* of Figs. 1 and 2 are quite parallel and give no apparent evidence for a relatively larger counting rate under the larger thicknesses of material for the showers of smaller angular divergence.

This last conclusion is more forcefully shown by a comparison of the 7° curve of Fig. 1 with

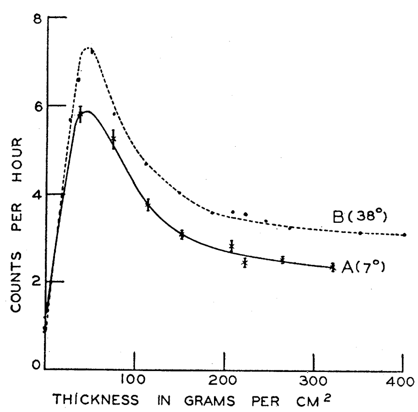

FIG. 3. A comparison of the data of curve *A* of Fig. 1 (full curve) with measurements previously reported, reference 3, (dashed curve) the ordinates of which have been divided by 2.5 for comparison purposes.

some of our earlier measurements[3] of the Rossi curve in which the angle subtended at the lower layers of material was 38°, and the actual counting rates (including background) have been divided by 2.5 for comparison purposes in Fig. 3. The curves are essentially alike. There is certainly no evidence here for a relatively increased counting rate at large thicknesses on the 7° curve.

The question naturally arises as to why two series of experiments such as those of Bothe and Schmeiser and those here presented should lead

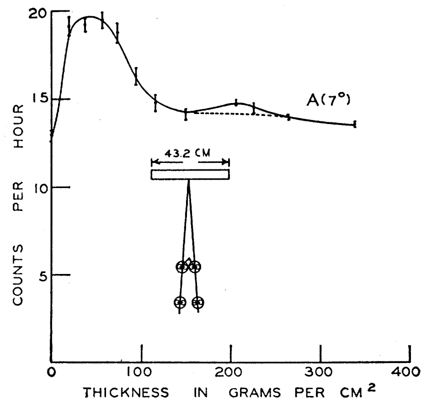

FIG. 4. Threefold coincidence counting rate of 7° showers from iron.

to such apparently different results. We have therefore modified our technique by connecting the two upper counters together as shown in Fig. 4. A similar arrangement was used by Bothe and Schmeiser. In this case triples are counted. The curve is not unlike that of Bothe and Schmeiser for 7° showers. In this case the added counting rate due to the iron is relatively very much less compared to the very large background. While Bothe and Schmeiser attempted to avoid complications caused by the background count, we are inclined to believe they have underestimated its importance in their work. Certainly it is significant that our own measurements show that the relatively high counting rate at large thicknesses is peculiar to an arrangement relatively insensitive to showers from the scattering material above it. We are therefore forced to conclude that our own measurements show that there is no significant difference in the ratio of counting rates at the first maximum to that under 200 g/cm² of iron, for either large or small angle showers, and that the processes which are responsible for the character of the transition curve under large thicknesses of a material are not necessarily restricted to small angles.

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