THE SECOND MAXIMUM OF THE ROSSI CURVE.

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INTRODUCTION.

During recent years great progress has been made in understanding the phenomenon of production of showers by high-energy electrons and positrons. It is known that such an electron (or positron), during its passage through matter, loses energy partly by ionization and partly by radiation. For every material there is a critical energy (E_c) at which the energy losses due to radiation and ionization are equal. If the energy of the particle is above the critical energy, the energy-loss due to radiation exceeds that due to ionization, while the reverse is true if the energy of the incident particle is less than E_c. This critical energy for lead is about ten million electron volts. A cosmic ray electron, whose energy is generally much higher than this amount, will at first lose its energy mainly by radiation during its passage through lead. The electron then radiates a few hard quanta which proceed in almost the same direction as the original electron and in their turn lose energy by creating pairs of positive and negative electrons. Each quantum gives rise to one pair of electrons which share the total energy of the quantum. Hence, if we had started with one primary electron of energy E_0 incident on a sheet of matter, after a small thickness is traversed, we are left with several electrons of both signs which have energies comparable to E_0.

Each of these electrons continues the process of generation of fresh quanta and ultimately of pairs of electrons. The size of the shower, *i.e.* the number of secondaries produced by the primary electron, increases and the energy of the shower electrons decreases as more and more matter is traversed. Finally, the critical energy of the material is reached when the energy-loss due to ionization becomes equal to that due to radiation. The ionization-loss becomes still more effective as the energy of the electron is further reduced. No multiplication therefore takes place and the electron is ultimately stopped due to its energy being completely lost by ionization.

This cascade theory of shower formation has been worked out in detail by Bhabha and Heitler (1937) as well as by Carlson and Oppenheimer (1937). Their theoretical predictions are confirmed in a very striking manner by the cloud chamber photographs of Fussell (1937), Trumpy (1938) and Street

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1939). In these photographs the successive stages of shower formation by radiation and pair-formation are clearly visible. From the work of Fussell it is also evident that the majority of the showers at the sea level are produced by the cascade process.

In order to study the showers released from a sheet of lead by the incident cosmic rays, Rossi (1934) employed a system of three counters arranged in such a way that the same particle cannot pass through all of them. If these counters are activated simultaneously a coincidence is recorded which indicates in general the release of two or more ionizing particles from lead. Rossi found that with his arrangement the number of coincidences increased with the thickness of lead used and that this number reached a maximum at a thickness of about 1·6 cms. of lead. Since the work of Rossi a great variety of counter and radiator arrangements have been used in order to study in detail the nature of the showers released from thin sheets (Froman and Stearns, 1938). As a result of these investigations it is now well established that the formation of showers under small thickness of matter and also the first maximum of the Rossi curve can be well explained by the cascade theory by assuming that they are caused by the soft component of the cosmic rays.

The showers under great masses of matter have been investigated by Follett and Crawshaw (1936), Ehmert (1937) and Morgan and Nielson (1937). As mentioned before the intensity of the cosmic ray showers in lead rises to a prominent maximum at about 1·6 cms. of lead, after which the shower, intensity falls rapidly with increasing thickness of the radiator. Beyond ten cms. of lead the rate of diminution becomes very small and the transition curve finally extends into a long tail with very little slope. Ackemann (1935), Hummel (1934), Drigo (1934) and Clay, Gemert and Wiersma (1936) showed that there is a second rise in the coincidence curve at a thickness much beyond that corresponding to the first maximum. They found that as the radiator thickness is increased, the shower frequency reaches a second maximum between 16 to 20 cms. of lead. This is known as the second maximum of the Rossi curve after which the shower frequency again diminishes. Bothe and Schmeisser (1938) made a detailed study of this second maximum and came to the conclusion that this becomes more prominent as the angle at which the shower is observed is reduced. At angles greater than ten degrees the second maximum is hardly noticeable, while at four degrees it is as prominent as the first. Bothe accounted for the failure of some of the early observers to detect a prominent second maximum to be due to their using wide angles.

By conducting the experiment under open sky and also in the cellar Bothe showed that the second maximum is produced by the penetrating component of the cosmic rays, a fact which is also evident from its position. Theoretically the exact mechanism by which mesotrons give rise to this second shower maximum is not very clear. A mesotron can initiate showers in two distinct types of processes. The first is the ionization shower postulated by Bhabha (1938). In this process a mesotron is supposed to knock out an extra-nuclear electron to which it gives less than half its kinetic energy. The knocked out electron subsequently produces an electron shower in the usual cascade process. Bhabha (1938) estimated that due to this process in lead mesotrons of energy of 10^{10} e.v. will be associated with soft electrons to the extent of fifteen per cent. According to Hopkins, Nielsen and Nordheim (1939) and Lovell (1939) the majority of the showers under thick layers of matter are fully accounted for by the Bhabha ionization process. Difficulties, however, arise as soon as attempts are made to explain the production of the second maximum of the Rossi curve by the Bhabha ionization process. A characteristic of these ionization showers will be that the primary mesotron will come out of the radiator associated with the shower particles which will be ordinary electrons. From the position of the second maximum and also the rate of absorption of the shower particles it appears that the shower particles in this case are not ordinary electrons but mesotrons.

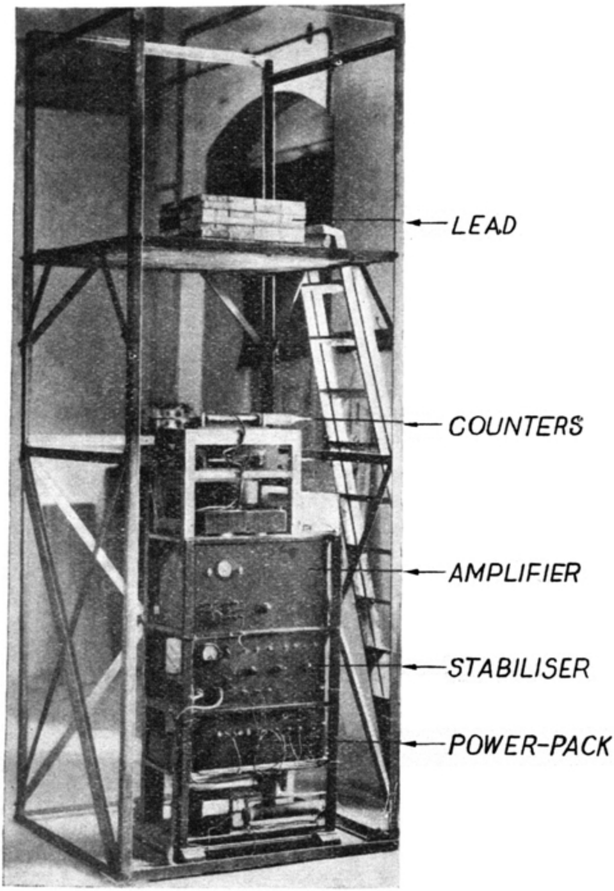
The other alternative in which mesotron showers may be produced is the multiple emission process, in which a heavy electron is absorbed or scattered by the nucleus and several heavy electrons are produced. The showers generated in this way have been investigated theoretically by Heisenberg (1939), Heitler (1938) and Wentzel (1938). But the occurrence of such close angle showers ($<10°$) as found by Bothe and Schmeisser cannot be explained on this theory unless some arbitrary cutting principles are introduced.

It will be evident from the above that the exact mode of origin of the second maximum is not very clear. It may be that the showers of both kinds are present in this maximum (Ehmert, 1939). Apart from these theoretical uncertainties great doubt has been thrown on the presence of this maximum by the recent work of Morgan, Nielsen and Nielsen (1939). They investigated showers under great masses of iron using four-fold coincidences for recording the showers. The showers at both 7° and 38° were recorded but no second maximum could be found in the shower curve, even though the radiator thickness was increased up to 300 gms./cm.^{2} As the four-fold coincidence method should be more sensitive to the showers from the top, the authors conclude that the second maximum found by Bothe and Schmeisser is due to background effect. It is, however, not clear why the background effect should occur only at a particular lead thickness.

On account of these theoretical and experimental uncertainties present in the second maximum of the Rossi curve it was decided to carry out a series of investigations on the second maximum using different experimental arrangements. The present paper contains an account of the preliminary work in which we have repeated Bothe's experiment with three-fold coincidence arrangement.

EXPERIMENTAL ARRANGEMENT.

The cosmic ray shower apparatus used in this experiment is shown in fig. 1. It consists of a massive iron frame capable of supporting a ton of lead above the counter assembly. The lead radiator, more than 20 cms. thick, which was formed with bricks piled upon one another can be seen at the top of fig. 1. The radiator covered a total surface area of 40×40 cm.^{2}



COSMIC RAY SHOWER APPARATUS

Fig. 1.

The counter assembly consisting of four counters, the amplifier with the thyratron recorder, the high voltage stabilizer for supplying voltage for the counters and the power-pack for the amplifier can be seen in fig. 1. The apparatus was made portable and suitable for outdoor work. The amplifier for recording four-fold coincidences was of Barasch (1934) type using a discriminator and a final pulse equalizing valve. The high voltage stabilizer using Street and Johnson's (1932) circuit was capable of supplying a high tension up to 3000 volts. Fig. 2 represents the arrangement of the counters.

Four counters were arranged at the corners of a trapezium below the lead radiator which was 77 cms. above the two lower counters; these subtended an angle of about 6° at the middle point of the lower surface of the radiator.

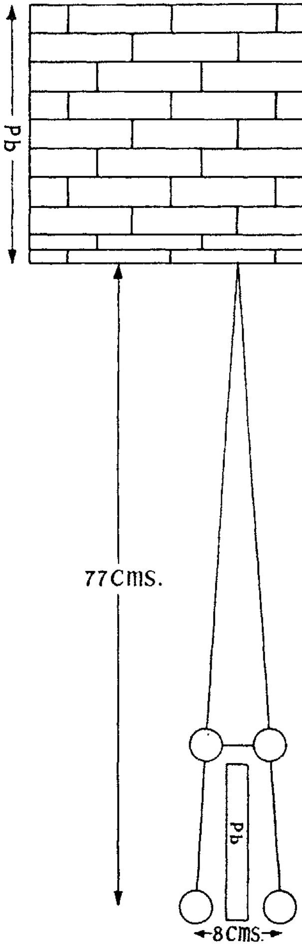


FIG. 2.

Only three-fold coincidences were recorded with the two upper counters connected in parallel. By this arrangement at least two shower particles were necessary to cause a coincidence. An intermediate sheet of lead 1·5 cm. thick was placed between the lower counters so as to stop the spurious coincidences caused by the electrons released from the counter walls passing from one into another. There was no absorber between the upper and lower counters.

Most of the measurements were made with brass counters 0·7 mm. thick, 2·5 cms. wide and having a working length of 20 cms. The counters were sealed in pyrex tube 0·4 gms./cm.^{2} thick. In order to cause a coincidence a cosmic ray particle had to traverse a total thickness of 3·75 gms./cm.^{2} including a piece of wood supporting the upper counters. From the calculations of Bethe and Heitler (1934) it was estimated that the cosmic ray particles causing the coincidences had energies exceeding 10 million electron volts.

RESULTS.

The following table indicates the results obtained with different thicknesses of the lead radiator placed on the top of the iron plate, quarter inch thick. This thickness of iron is equivalent to a thickness of about 0·2 cms. of lead, according to Bhabha's theories. This constant thickness of 0·2 cms. has been added to the actual lead thickness in order to get the figures given in column (1) under the head 'total thickness of the lead radiator'.

As the number of coincidences per hour was small, each reading had to be extended over a great length of time in order to count a sufficient number of coincidences, to reduce the statistical errors. The total number of coincidences counted is indicated in column (3), while the total time involved in each reading is given in column (2). The rate of coincidences per hour has been indicated in the last column with the probable error ·68 $\sqrt{N}/T$ where $N =$ total number of coincidences and T the total time of counting. No correction has been made for the accidental coincidences, calculation showed that they would be about 0·85 per hour. The results are shown plotted in fig. 3 where the probable error in determination has been indicated by vertical lines.

TABLE I.

Total thickness of the Pb radiator in cms.	Total time of counting in minutes.	Total number of coincidences counted.	Coincidence per hour.
·2	498	68	8·2 ± ·67
1·2	724	122	10·5 ± ·64
2·2	656	104	9·5 ± ·63
4·7	1139	147	7·7 ± ·44
7·2	1550	147	5·7 ± ·32
9·7	704	59	5·0 ± ·44
12·2	786	64	4·9 ± ·42
14·7	1075	74	4·1 ± ·32
17·2	1002	91	5·5 ± ·39
19·7	1236	129	6·3 ± ·38
22·2	541	47	5·2 ± ·52

From the curve shown in fig. 3 it will be evident that the coincidence curve has two prominent maxima of comparable intensities. The second maximum occurs at a thickness of lead of about 18·5 cm. which is slightly greater than that found by Schmeisser and Bothe (16·5 cm.). The intensity of the first maximum is much reduced as only close angle showers were observed and the experiment was carried out under one layer concrete roof of thickness 20 cms. approximately. This cuts off some of the softer components of the incident cosmic radiation. The second maximum is, however, unaffected by such small thickness of matter. The occurrence of the second maximum at 18·5 cms. is in very good agreement with the calculations of Ehmert (1939) based on the absorption coefficient of the shower particles.

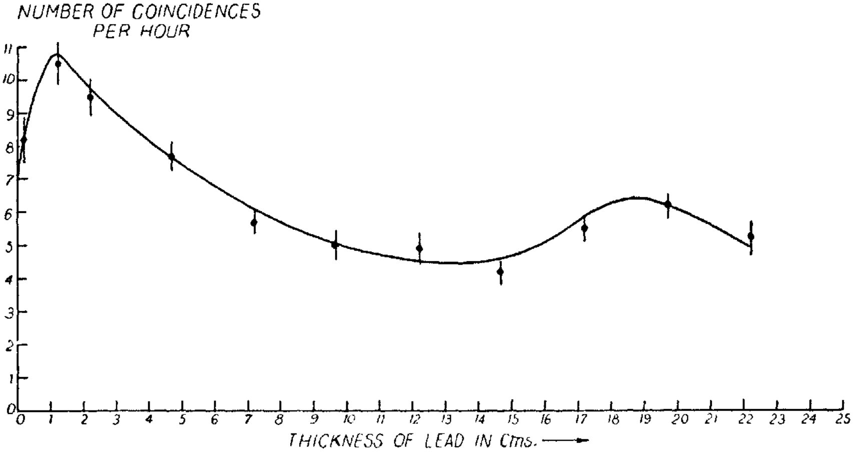


FIG. 3.

The first maximum occurs at 1·3 cm. of Pb thickness which is slightly less than the usually accepted value of 1·6 cm. No great care was, however, taken to determine its position very accurately, as the chief interest of the experiment was to test the presence of the second maximum if any. It will be apparent from fig. 3 that there are many coincidences even with no Pb radiator placed above the counters. These are due to showers from air, roof, walls, etc. which are partially absorbed by increasing the thickness of the Pb radiator. The second part of this background effect is not affected by placing Pb over the counters. As found by Bothe and Schmeisser it is not possible to avoid completely this background effect. However, the presence of two maxima in the shower curve is clearly proved by the results of the present experiment.

The experiment was carried out in the Cosmic Ray Research section of the University College of Science at Calcutta. It is with great pleasure the writer acknowledges his grateful thanks to Prof. M. N. Saha, D.Sc., F.R.S., for his kind interest and encouragement in this line of research. My thanks are also due to Dr. S. C. Sirkar and Mr. P. C. Bhattacharya for helpful discussions.

SUMMARY.

Cosmic ray showers from lead have been investigated with three-fold coincidence arrangement up to a total thickness of 22 cms. of lead. The minimum angle subtended by the shower particles at the lower surface of the radiator was 6°. With this arrangement the shower curve shows two prominent maxima at 1·3 cms. and 18·5 cms. of lead.

REFERENCES.

Ackemann, 1935, *Zs. f. Phys.*, **94**, 303, 816.
Barasch, 1934, *Prof. Phys. Soc.*, **47**, 824.
Bethe and Heitler, 1934, *Proc. Roy. Soc.* A, **146**, 83.
Bhabha, 1938, *Proc. Roy. Soc.* A, **164**, 257.
Bhabha and Heitler, 1937, *Proc. Roy. Soc.* A, **159**, 432.
Bothe and Schmeisser, 1938, *Ann. Phys.*, **32**, 161.
Carlson and Oppenheimer, 1937, *Phys. Rev.*, **51**, 220.
Clay, Gemert and Wiersma, 1936, *Physica*, **3**, 626.
Drigo, 1934, *Ricerca Scient.*, **3**, 88.
Ehmert, 1937, *Zs. f. Phys.*, **106**, 751.
Ehmert, 1939, *Zs. f. Phys.*, **113**, 234.
Follett and Crawshaw, 1936, *Proc. Roy. Soc.* A, **155**, 546.
Froman and Stearns, 1938, *Rev. Mod. Phys.*, **10**, 145.
Fussell, 1937, *Phys. Rev.*, **51**, 1005.
Heisenberg, 1939, *Zs. f. Phys.*, **113**, 61.
Heitler, 1938, *Proc. Roy. Soc.* A, **166**, 529.
Hopkins, Nielsen and Nordheim, 1939, *Phys. Rev.*, **55**, 233.
Hummel, 1934, *Naturwiss.*, **22**, 170.
Lovell, 1939, *Proc. Roy. Soc.* A, **172**, 568.
Morgan and Nielsen, 1937, *Phys. Rev.*, **52**, 564.
Nielsen, Morgan and Morgan, 1939, *Phys. Rev.*, **55**, 995.
Rossi, 1934, *Int. Conf. Phys.*, **1**, 233.
Street, 1939, *Jour. Frank. Inst.*, **227**, 765.
Street and Johnson, 1932, *Jour. Frank. Inst.*, **214**, 155.
Trumpy, 1938, *Nature*, **141**, 909.
Wentzel, 1938, *Phys. Rev.*, **54**, 869.