Experiments on the Separation of Low Energy Mesotrons from Electrons

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For the separation of low energy mesotrons from the electrons a block of lead 1.25 cm thick was placed above a pair of anticounters such that any electron which generates a shower in it is removed by the anticounters. An additional block of lead was also placed below the anticounters to absorb any electron which escaped the system without producing a shower in the upper lead piece. The mesotrons thus separated from the electrons were examined in a Wilson chamber having a 2-cm block of lead across the center. 937 single tracks were observed to traverse the 2-cm lead block and all these tracks were ascribed to mesotrons. There was a case of a shower of three particles found to be generated in the lead piece inside the chamber and this shower was attributed to a knock-on process. It was also found out that the additional lead block whose thickness was to be 4 cm, according to Bhabha, could be reduced to 2 cm at sea level without disturbing the efficiency of the system.

By an experiment with counters it was also found out that 1.25 cm of lead corresponds to the maximum for showers of two or more particles initiated only by electrons in lead.

I. INTRODUCTION

IT is known that the mesotrons occur only in cosmic radiation—in fact, the penetrating component consists practically of mesotrons while the soft component consists of electrons, positrons, and photons. The soft component is absorbable in a few centimeters of lead and produces cascades in traversing dense material like lead. It is only for these properties that the electrons can be eliminated from the mesotrons. In order to get rid of them the usual practice is to put 10 cm of lead between Geiger-Müller counters but the defect of this method is that the filter while absorbing the soft component absorbs also all the mesotrons of range up to 10 cm of lead, i.e., of energy up to 2.4×10^8 ev as can be seen from the range-energy curves of Rossi and Greissen.[1] The number of these low energy mesotrons increases with altitude. Experiments of Malcolm Correll[2] suggest that the slow mesotrons of energy between 8×10^7 ev and 2×10^8 ev at 11,500 ft are produced by a neutral radiation although the more energetic mesotrons are believed to be produced by the protons. Similarly, the other characteristics of slow mesotrons are likely to be quite interesting. But most of these low energy mesotrons are lost in the thick absorber in the process of separation. In order to study their properties it was decided to undertake first of all, experiments to separate the mesotrons from the electrons using as little of lead absorber as possible. Furthermore, in balloon experiments for measuring mesotron intensity at high altitude it will be an advantage if we can use smaller thickness of lead as filter.

Recently Bhabha[3] suggested a method for the removal of electrons by making the most effective use of the cascade process. In this method a block of lead 1.25 cm thick was used to produce showers. It was placed just below the topmost counter of the telescope and over a counter tray containing two sets of counters attached to an anticoincidence circuit such that any shower produced in the lead piece were suppressed by the anticounters. A second piece of lead, 4 cm thick was placed below the anticounters but above the lowest counter of the telescope. The function of the second lead piece was to absorb any low energy electron which escaped the system without producing a shower in the upper lead block. Thus, with this arrangement one is expected to have mesotrons of energy as low as 1.6×10^8 ev, i.e., of range 5.25 cm of lead.

It will be interesting to test experimentally with a Wilson chamber to see how far this suggested arrangement is correct. For this purpose the four-centimeter lead block of Bhabha

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[1] Bruno Rossi and Kenneth Greissen, Rev. Mod. Phys. **13**, 240 (1941).

[2] M. Correll, Bull. Am. Phys. Soc. **22**, 27 (1947).

[3] H. J. Bhabha, Proc. Ind. Acad. Sci. **19**, 23 (1944).

was further divided into two pieces of 2 cm each, and one of them was placed across the middle of the Wilson chamber while the other one was placed just above the lowest counter. The lead piece across the chamber served to distinguish between electrons and mesotrons. An electron has a large probability of producing secondaries in traversing the lead block while a mesotron will come out as a single particle.

In regard to the thickness of the upper lead block an experiment with counters was carried out to ascertain the exact thickness of lead corresponding to the shower maximum of more than one particle and more than two particles initiated by electrons in lead. Calculations of the probabilities of showers of more than one particle and more than two particles were also carried out by the author.[4] These calculations were made on the assumption that fluctuations obey Poisson distribution and that the energy spectrum of the electrons incident on the top lead block is of the form $J(K/E)^{\alpha}$ where J and K are suitable constants and $\alpha = 2.9$ at sea level. It is shown in that paper that the probability curves show a maximum at absorber thickness of 1 to 2 radiation units and that the maximum depends on the lower limit of the energy spectrum. It is further shown there that we can have a number of theoretical curves for showers of more than one particle and more than two particles corresponding to the different low energy limits of the energy spectrum and that the curves which fit well with the experimental one can give an idea of the low energy limit of the incident electron spectrum.

II. EXPERIMENTAL

A. Counter Experiment for Showers

The Geiger-Müller counters used in these experiments were each 15 cm long and 4 cm in diameter; the outer electrode was of thin copper foil and the central one was of 3–4 mil-tungsten wire. They were sealed in Pyrex glass tubes with a mixture of alcohol vapor and argon. The starting potential of these counters was about 1000 volts with a plateau of about 300 volts. The efficiency of these counters was found to be in the range 98.6 to 99.8 percent. The counters were used in Rossi parallel connection and the resolving time of the circuit was found to be of the order of 10^{-5} sec.

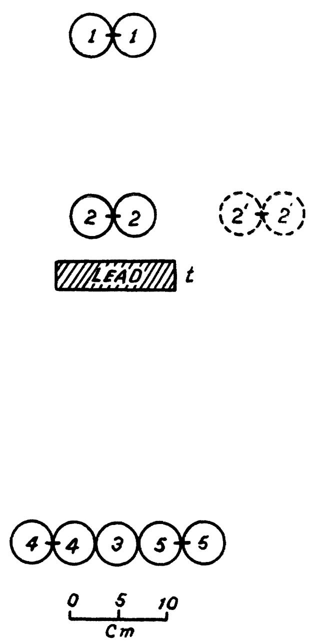

FIG. 1. Arrangement of counters for determining the shower maximum for more than one particle and more than two particles in lead. Each of the counters 1, 2, 4, and 5 are, in fact, two counters joined in parallel.

In order to determine the shower maximum of more than one particle and more than two particles, the counters were arranged as in Fig. 1. Each of the counters 1, 2, 4, and 5 were, in fact, two counters joined in parallel. The circuits were used in such a way that the coincidences C_{12345} or $C_{123(4+5)}$ were recorded simultaneously with coincidences C_{123}. For recording the coincidences $C_{123(4+5)}$ the counters C_4 and C_5 were joined in parallel. Lead blocks of different thicknesses were placed at t and records taken in a cyclic manner so as to avoid any instrumental selectivity. Further, the coincidences C_{123} due to

TABLE I. Data for side showers, etc. for different thicknesses of lead.

Lead in cm	Fourfold coincidences $C_{123(4+5)}$ No. of counts	Time in hours	Rate (counts per hour)	Fivefold coincidences C_{12345} No. of counts	Time in hours	Rate (counts per hour)
0	217	221	0.982 ± 0.0449	91	201	0.4527 ± 0.0318
1	208	204	1.020 ± 0.0473	96	207	0.4637 ± 0.0317
2	212	210	1.009 ± 0.0464	92	200	0.4601 ± 0.0321
4	218	220	0.991 ± 0.0447	89	$197\frac{1}{2}$	0.4506 ± 0.0320

[4] Proc. Nat. Inst. Sci., India, *in press*.

TABLE II. Data for showers of two or more particles.

Lead in cm	No. of counts	Time in hours	Fourfold coincidences $C_{123(4+5)}$ Counting rate per hour	Counting rate corrected for showers, etc.
0.0	514	140½	3.659±0.1081	2.677±0.1170
0.5	387	60	6.449±0.2197	5.429±0.2247
1.0	439	61½	7.139±0.2282	6.119±0.2328
1.5	394	63	6.255±0.2111	5.235±0.2160
2.0	355	71	5.000±0.1778	3.991±0.1835
2.5	385	89	4.326±0.1477	3.317±0.1546
3.5	207	74	2.688±0.1252	1.697±0.1323
4.5	176	77	2.286±0.1154	1.295±0.1233

TABLE III. Data for showers of three or more particles.

Lead in cm	No. of counts	Time in hours	Fivefold coincidences C_{12345} Counts per hour	Counting rate corrected for showers, etc.
0.0	255	278	0.917±0.0385	0.465±0.0499
0.5	273	139	1.964±0.0797	1.500±0.0860
1.0	210	90	2.333±0.1079	1.869±0.1123
1.5	233	122	1.910±0.0838	1.446±0.0894
2.0	288	175	1.646±0.0649	1.185±0.0721
2.5	149	102	1.461±0.0802	1.001±0.0860
3.5	192	175	1.097±0.0531	0.647±0.0616
4.5	155	172	0.901±0.0485	0.451±0.0583

single particles were recorded simultaneously either with C_{12345} or with $C_{123(4+5)}$ as a check on the data for showers. The side showers, etc., were determined by shifting the counter 2 to a distance denoted by a dotted line in the figure, other counters being kept at their previous position. These counting rates were subtracted from the experimental rate of showers to get the real shower rate. The shower correction for intermediate thicknesses of lead, *viz.*, 0.5, 1.5 cm, etc., were made from the graphical interpolation. The data for side showers, etc., are given in Table I while the experimental results are given in Tables II and III. These results are plotted in Fig. 2. The top curve shows the shower of two or more particles and the bottom one the shower of three or more particles. The dotted curves show the theoretical results for different low

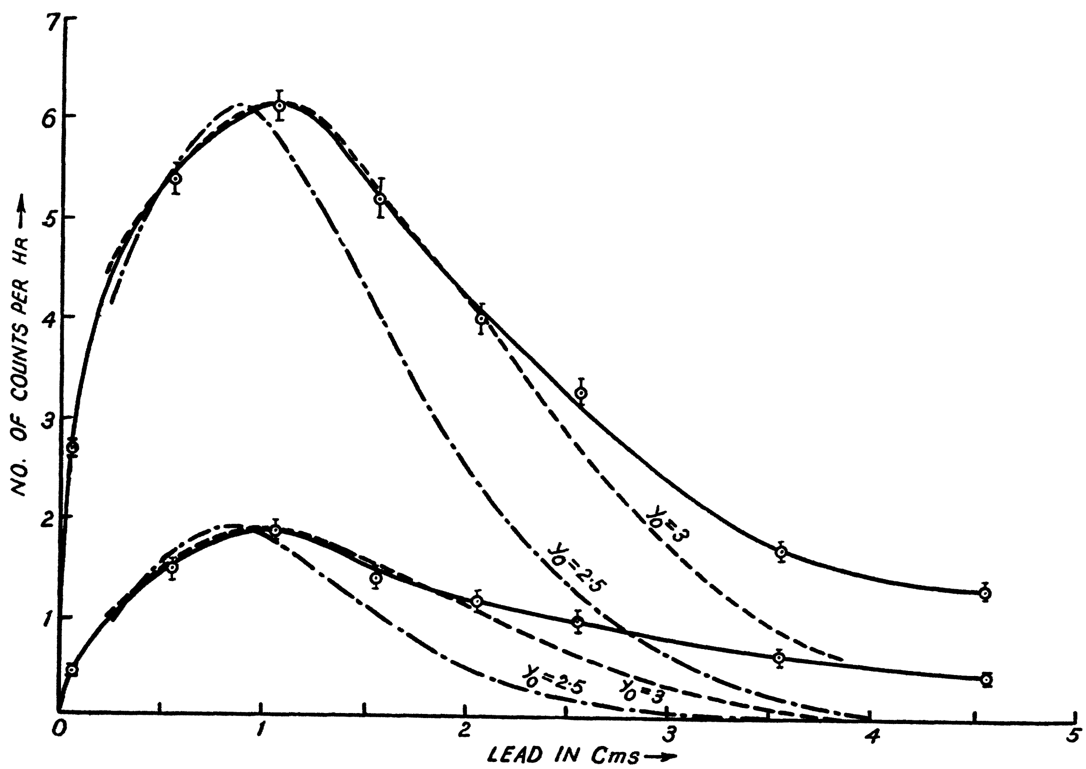

FIG. 2. The top solid curve shows the experimental result for showers of two or more particles in lead and the bottom one for showers of three or more particles. The dotted curves denote the theoretical results for different low energy limits of the incident electron spectrum corresponding to different values of y_0. Since $E=\beta e^{y_0}$ where $\beta=6.9\times10^6$ ev in lead, we find that $y_0=3$ corresponds to electrons of energy 1.4×10^8 ev.

energy limits of the incident electron spectrum corresponding to different values of y_0 which are written on the curves themselves. These theoretical curves were normalized at the maximum, and while comparing these curves with the experimental ones proper care was taken regarding their abscissa. To convert the abscissa of the calculated curves in thicknesses of lead, they are to be multiplied by 0.52 cm.

From the experimental curves for showers of more than one particle and more than two particles it will be seen that about 1.25 cm of lead corresponds to the shower maximum of both the curves. It will be also seen that the calculated curves corresponding to $y_0=3$ for more than one particle and more than two particles practically coincide in the neighborhood of the maximum of both the experimental curves. In the tail of the transition curves the deviation of the theoretical curves from the experimental ones is very pronounced, as it should be. The theoretical curves drop practically to zero between 4 and 5 cm of lead while the experimental ones maintain some high level. As $y_0=3$ corresponds to electrons of energy 1.4×10^8 ev, the lower limit of the energy spectrum of electrons incident on the top of the upper lead block appears to be equal to 1.4×10^8 ev. But electrons of energy lower than this are known to exist at sea level from the experiments of Williams[5] and others. The discrepancy may be due to the fact that the theoretical calculations do not hold well at such low energy. Moreover, the experiment was carried out in the room of a one-story building and, consequently, some of the low energy electrons were cut off. It can be seen also that our experimental arrangement is likely to miss some showers.

B. Experiment with Counter Controlled Wilson Chamber

In order to examine the mesotrons separated from the electrons a lead block 2 cm in thickness was placed across the Wilson chamber and the relative positions of counters and lead blocks with respect to the chamber are shown in Fig. 3. A particle which traverses the 2-cm lead plate as a single particle without appreciable deflection is taken to be a mesotron.

[5] E. J. Williams, Proc. Roy. Soc. **172**, 194 (1939).

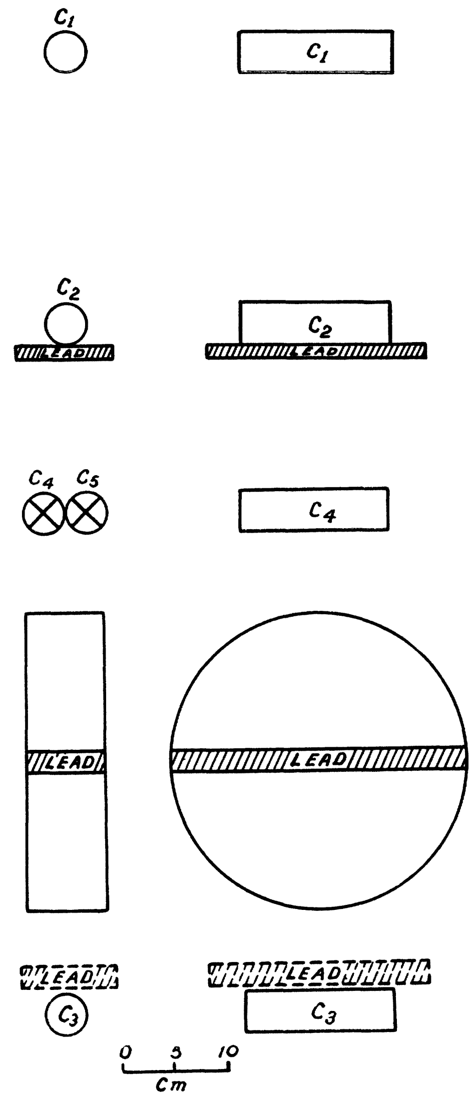

FIG. 3. Side and front view of the arrangement of counters, etc., with respect to the Wilson chamber. C_4 and C_5 are the counters connected to the anticoincidence circuit. The lower lead block shown dotted was removed in some of the observations.

The counters C_4 and C_5 were connected to a circuit such that the coincidence pulse C_{45} was reversed by a valve and fed to the grid of a thyratron through a condenser. The coincidence pulse C_{123} is also fed to the grid of the same thyratron through another condenser. The pulses C_{45} and C_{123} are in opposite phase so that if they arrive at the grid at the same instant there will be no record, i.e., the system will not register any single particle accompanied by a shower of

TABLE IV.

Coincidences	No. of counts	Time in hours	Counts per hour	Soft:hard
C_{123}	160	17	9.4	22 percent
$C_{123-(45)}$	154	20	7.7	

two or more particles exciting both C_4 and C_5 simultaneously. So the pulses $C_{123-(45)}$ are due to single particles which are not accompanied by a shower of at least two particles exciting C_4 and C_5. The efficiency of this anticoincidence circuit was found to be 97.7 percent.

The anticounters C_4 and C_5 were placed just above the chamber and the area covered by them in the chamber was illuminated at the time of exposure. The lead block 1.25 cm thick was placed at such a distance from the anticounters that the shower rate was the maximum as was determined by a subsidiary experiment. The lateral spread of showers of two or more particles was found by counters in the present experiment to be about 24° (cf. Held[6] who found it to be 22°). A counter experiment was performed with this arrangement and the ratio of soft to hard was determined. The pulses C_{123} record the total intensity of electrons and mesotrons. The pulses $C_{123-(45)}$ record the intensity of single particles not accompanied by secondaries, i.e., the intensity of mesotrons. Thus $[(C_{123})-(C_{123-(45)})]/C_{123-(45)}$ gives the ratio of the soft to hard component of cosmic rays. Table IV shows the result of soft:hard with 3.25 cm of lead—1.25 cm being placed at the top for producing showers and 2 cm piece being placed at the middle of the Wilson chamber.

TABLE V

	1.25-cm lead at the top and 2-cm block across the chamber	No. of photos	Time in hours	Information extracted
1	2-cm lead over the counter C_3	523	86	435 single particles traversed the lead plate with one three-particle shower produced in the lead plate.
2	Without lead over the counter C_3	620	100	502 single particles traversed the lead plate without producing any shower in it.

[6] Held, result not published, see Geiger, Ergeb. d. exakt. Naturwiss **14**, 42 (1934).

The Wilson cloud chamber was of the Blackett type. It was 30 cm in diameter and 10 cm in depth. It contained oxygen and air at a pressure of about 96 cm mercury and the liquid mixture was of alcohol and water. Eight 100-watt, 110-volt, straight filament lamps were used for the illumination. The beam was collimated by eight spherical lenses. Normally the filaments were kept dull red, but they were "flashed" by putting instantaneously 220 volts at the moment when a cosmic particle traversed the chamber. The camera was normally kept open in the dark and after each exposure the film was wound by a mechanical device driven by a motor. The camera lenses were Aldis F/3, 5-cm focal length, and the film was the Kodak panchromatic super XX, 35 mm-size.

The working of the Wilson chamber was automatic and the expansion of the chamber was controlled by the pulses $C_{123-(45)}$. After each expansion the chamber remained inactive for about 120 sec., when three slow expansions occurred to clear the chamber from old ions. There was no magnetic field in the chamber. Table V shows the result of two runs. The expansion of the cloud chamber per hour were little less than the counting rate and this is expected as the chamber remained inactive for sometime after each expansion. 937 single tracks were observed to traverse the 2-cm lead piece at the middle of the Wilson chamber but only one shower of three particles was found to be generated in the lead piece. This shower might be due to a knock-on process, i.e., a mesotron while traversing the lead block knocked out an electron imparting sufficient energy to it and that electron might produce the shower by the cascade process.

There were 15 cases in which one secondary was found to accompany the primary in the upper half of the chamber. This might be caused by the inefficiency of the anticounter circuit. This might also happen when both the shower particles pass through any one of the anticounters, *viz.*, C_4 or C_5, when there would not be any coincident pulse C_{45} so that the particle would be recorded as due to the pulse $C_{123-(45)}$. This defect seems to be inherent in the present arrangement of counters.

III. DISCUSSION

Schein, Jesse, and Wollan[7] also used side counters to eliminate the electrons which produced showers in the lead block. The distance of the lead block from the side counters was not mentioned by them. It is found here that the relative position of the lead block and the counters is very important. The upper lead block of 1.25-cm thickness should be placed at such a distance from the anticounters that the showers generated in it have the maximum chance of operating the anticounters. In the present investigation this distance was found to be about 15 cm.

The method of separation of mesotrons by placing 1.25 cm of lead above a pair of anticounters and another lead piece of 4-cm thickness below the anticounters, as was originally suggested by Bhabha, was found to be quite efficient in sorting out the mesotrons. With this arrangement we can study mesotrons of energy as low as 1.6×10^8 ev, i.e., of range 5.25 cm of lead. This arrangement can be used for measuring the mesotron intensity at high altitudes.

Now the question arises as to whether the additional block of lead of 4-cm thickness is absolutely necessary or whether it can be reduced or totally dispensed with in case we want to study mesotrons of range lower than 5 cm of lead.

[7] M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **59**, 615 (1941).

We have found 15 cases in which a secondary was found to accompany the primary in the upper half of the Wilson chamber. The probable causes for these have already been discussed. The most plausible reason is that all the particles of the shower pass through either of the anticounters C_4 or C_5 and in such cases the anticoincidence circuit does not give any pulse, so that we get a pulse $C_{123-(45)}$ which is ascribed to a mesotron although it is due to a shower particle. It is also shown in my paper (in press) that the chance of missing such showers increases with showers of fewer particles. Such cases will be more frequent if we totally discard the lower lead block. Thus the lower lead block appears to be indispensible for absorbing these showers of fewer particles and also for absorbing the low energy electrons which escape the system without producing a shower in the top lead block.

As regards the thickness of this lead block we have seen that at sea level it can be reduced to 2 cm without affecting the efficiency in the system, i.e., mesotrons.

In conclusion, the author expresses his indebtedness to Professor M. N. Saha for his kind interest and encouragement throughout the progress of the work. Thanks are also due to Dr. N. Das Gupta and Mr. S. K. Ghosh for discussions and criticisms and also for the latter's assistance in taking some of the observations.