THE METHOD OF SHOWER ANTI-COINCIDENCES FOR MEASURING THE MESON COMPONENT OF COSMIC RADIATION

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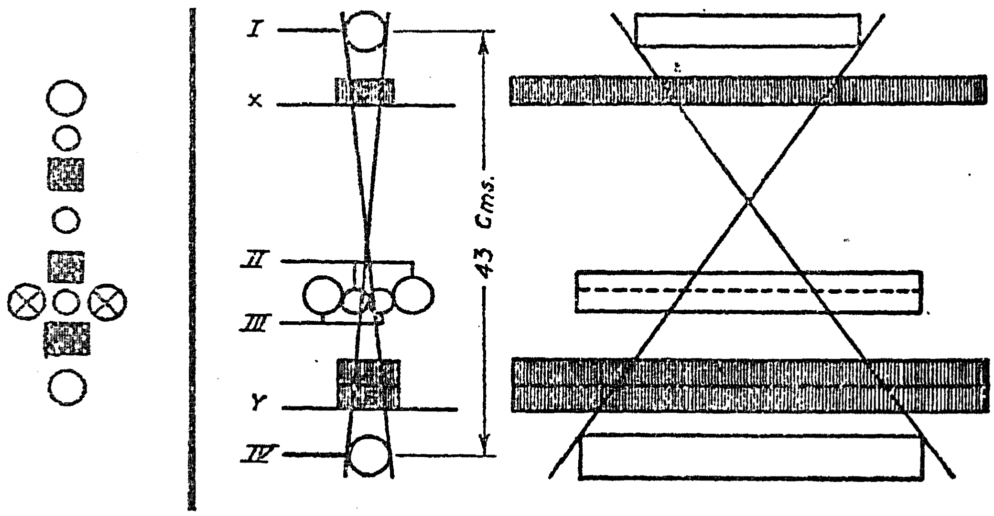
1. *Introduction*

IT is comparatively simple enough to distinguish between ionising particles of electronic and of heavier mass in the Wilson Chamber as long as the energy of the particles is not too high. In experiments with Geiger counters however, there is no direct and simple way for identification of the type of the particles, and so far the criterion of penetrability has been the one most widely used for differentiation of the two main components of cosmic radiation. Bhabha[1] has however pointed out how it is necessary to use 7·9 cm. of lead in order that all but 2% of the electronic component can be stopped. This naturally puts a limit to the minimum energy of the meson component that is measured. When therefore we try to measure the meson component by filtering out the soft electronic component with 7·9 cm. of lead, we measure in fact only mesons with energy greater than $1 \cdot 3 \times 10^8$ e.v. It is known however that there are mesons of less energy in the cosmic ray spectrum. According to Blackett,[2] all particles with energy less than 2×10^8 e.v. behave like electrons in their energy loss, but Anderson and Neddermeyer[3] find penetrating particles with less energy and have pointed out that Blackett's figure should be actually only $1 \cdot 1 \times 10^8$ e.v. Williams[4] has investigated the low energy spectrum, but has not made observations on the energy loss, and takes Blackett's observations to conclude that all the particles that he investigated in the low energy region were of electronic mass. More recently Bostick[5] has found evidence for slow mesons in a Wilson Chamber at 14,000 ft., and it is becoming increasingly clear that slow mesons are present in the cosmic ray spectrum. Rossi and Griesen[6] estimate that the slow mesons which get absorbed by 15 cm. of lead form 7% of the total meson intensity at an altitude of 850 ft., but may be as high as 27% at 14,100 ft. The results of Schein *et al.*[7] also point to the fact that the intensity of slow mesons increases rapidly with altitude.

Of late, the problem of knowing the correct proportion of electrons and mesons in the atmosphere at various altitudes has attracted a great deal of attention. Auger[8] and Griesen[9] have utilised accurate absorption experiments with lead and iron absorbers in order to get an estimate of not only the electron (soft) component, but also the meson (hard) component. In order to arrive at the slow meson component which he finds to be about 8%, Griesen has to make correction for what he calls the "Collision and Shower Effects". The estimation of the latter is perhaps the only weak link in an otherwise beautiful analysis. Stimulated by the idea of Bhabha to utilise the generation of secondaries of the soft component in order to exclude it, the author has tried out a new experimental arrangement for obtaining the intensity of slow mesons. The importance of this method lies not so much in reducing the weight of lead for measuring the meson intensity in balloon experiments, or in the exclusion of high energy electrons as in bringing for the first time the slow mesons in the field of direct experimental measurements.

2. *Method of Shower Anti-coincidences*

It has been found experimentally that a good proportion of the electrons measured by a cosmic ray telescope are already associated in the atmosphere with other ionising particles. The number so associated can be increased by placing in the apparatus a block of lead of thickness corresponding to the observed maximum of the Rossi curve. In order to exclude the



(*a*) (*b*)

FIG. 1. (*a*) Showing the arrangement of Jesse *et al.*
(*b*) Showing the experimental arrangement used for measuring shower anti-coincidences.

electrons, we can then devise an arrangement whereby the arrival of the associated particle can be cancelled by an anti-coincidence arrangement, and keep just so much additional lead underneath to absorb low energy electrons which might emerge from the top lead unaccompanied by other shower particles. In fact Schien, Jesse and Wollan[10] have utilised the phenomenon of shower production for making sure that the electron component was not greatly affecting the meson intensity that they measured in their balloon experiments with varying amounts of lead used to filter out the soft component. They measured events in which counters on the sides registered a particle associated with the penetrating particle in the main cone, as shown in Fig. 1 (*a*). Such an arrangement with the side counters working in anti-coincidence was initially suggested by Bhabha, but while on the basis of Auger's results, the atmospheric showers on account of their large spread will be probably quite well detected by this arrangement, the showers generated in the lead above may not be registered equally well on account of their small spread. In order to increase the efficiency of detection of both the atmospheric showers and those generated in the lead, it is desirable not to exclude the area of the main cone of measured radiation for the registering of the showers. This, however, cannot be accomplished by the use of the usual anti-coincidence arrangement, and a circuit is now devised whereby it is possible to tackle the main cone by placing two sets of counters in and adjoining the cone of the measured radiation (Fig. 1 *b*) and arranging matters so that only a coincidence between these two sets will cancel the event. This arrangement is simpler than the one now mentioned by Bhabha[1] and when used with quadruple coincidences would ensure that side showers do not vitiate the result. The circuit used for measuring the shower anti-coincidences is shown in Fig. 2. The two sets of anti-counters are connected in a Rossi coincidence arrangement with their mixer tube serving the dual role of a shower discriminator and a pulse reverser feeding the shower anti-pulse to the main coincidence circuit. Even though this means that the anti-pulse is fed through two stages as against the one stage for the main coincidence pulse, it is possible to attain an efficiency of 100% in the registration of shower anti-coincidences. The efficiency was measured in the following way:

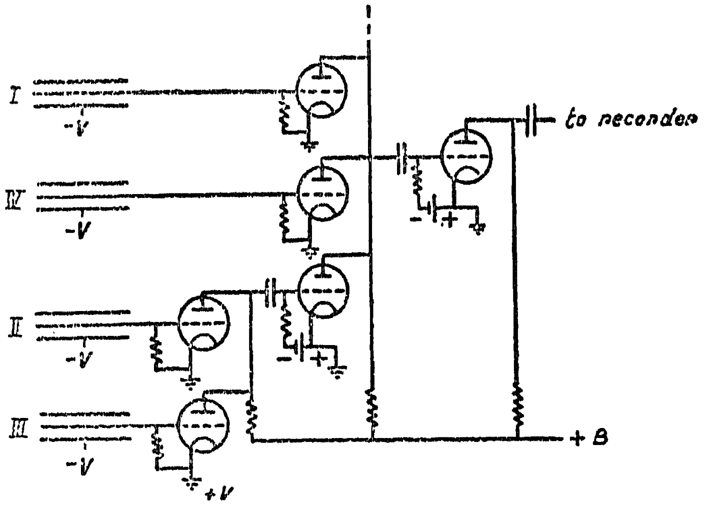


FIG. 2. Basic circuit used for measuring shower anti-coincidences. All tubes are Marconi Z21 and details are omitted.

An array of 4 counters A, B, C, D comprised a vertical telescope. The two end counters A, D were smaller both in length and diameter than the two middle counters B, C of the telescope. This ensures that every particle coming in the main cone determined by A, B will pass through the sensitive volumes of counters B, C. The double coincidences AD and the quadruple coincidences ABCD were measured. The difference in these two rates should be due to the effect of side showers and the inefficiency of counters B and C. This should equal the shower anti-coincidence rate AD –(BC) where the two centre counters are connected individually to the shower anti-coincidence tubes. The agreement of these counting rates was within a statistical accuracy of 1%. In order to see whether the feeding of one anti-pulse had any effect on the efficiency of registration of the main anti-coincidence rate AD, it was compared with the counting rate AD–(C) and the rate AD–(B) wherein the anti-pulse was fed to only one of the shower coincidence tubes. No effect falling outside the statistical accuracy of the measurements was found.

The circuit for the measurement of shower anti-coincidences is now being utilised for an accurate study of the intensity of slow mesons, and the results will be communicated later. However, a preliminary test has been made at various altitudes in Kashmere during August and September 1943, and the results of this preliminary survey are presented below.

3. *Preliminary Survey of Meson Intensity at Various Altitudes in Kashmere*

In August 1943, an expedition was undertaken to Kashmere in order to find suitable locations where high altitude cosmic ray experiments could be performed. Though at that time the work on the experiment for measuring the slow meson intensity by the method of shower anti-coincidences had not progressed very far, it was decided to conduct that experiment at various altitudes in Kashmere to give a preliminary idea of both the working of the method of shower anti-coincidences and of the experimental technique involved in carrying out experiments on high peaks of the Himalayas. The most suitable period during which ascents can be undertaken to altitudes higher than 12,000 feet is from the middle of August to the middle of September. This consideration made it imperative to undertake the expedition in spite of the fact that the ideal experimental conditions for the method of shower anti-coincidences had not then been fully worked out.

A completely battery operated unit for registering fourfold coincidences along with shower anti-coincidences was set up. Marconi Z21 tubes were used for the amplifier on account of their low filament current drain, and the mechanical recorder was operated by a type 31 tube in the final stage. The B supply was furnished by a Stabilovolt regulator tube fed from a Vibrapack operated from one of two 6 volt accumulators taken with the expedition. The accumulators were charged at the location of the experiment by means of a petrol generator set which was carried to all altitudes except the highest. The high voltage for the counters was obtained from a small unit of dry cells made up of Eveready type 712 cells connected in series. The counters were operated 50 volts above threshold potential and were all well within the flat portion of their plateau. The counters were mounted on a portable wooden stand, and the exact geometrical arrangement is shown in Fig. 1 (*b*). It was found that within the main cone the efficiency of registering showers was greater with narrow counters than with counters of large diameter, but that outside the main cone the larger the sensitive volume used, the larger was the measured shower effect. The counters comprising the shower detecting tray were therefore of two diameters. The top counter I of the telescope measuring the vertical intensity was of smaller length than the others in order to ensure that the area of the block C included in the main cone was smaller than the area of the shower detecting tray. Electrons arriving along the boundary of the main cone will thus have a greater chance of being cut out by the showers they would generate in C.

The experiment was attempted at 5 different altitudes in Kashmere. It was first tried near Gangabal at Tronkhal (11,000 ft.) and then at Cosmic Ray point (13,900 ft.). Good consistent results were obtained at both these locations. It was then attempted at Srinagar (5,200 ft.) and, in order to obtain a check on the Gangabal results, at Gulmarg (8,900 ft.) and near Alpathar (12,800 ft.). Unfortunately, the Srinagar results were not satisfactory, and it was not possible to repeat them for want of time. At Alpathar, the shower anti-coincidence arrangement did not work on account of what was later detected to be the failure of one of the Z21 tubes. However, the total cosmic ray intensity was measured and has been used as a check on the other points. While all the experiments at Kashmere were carried out at geo-magnetic latitude 25° N., the experiment has been repeated at Bangalore (3,000 ft.) at geo-magnetic latitude 3° N. The latitude effect does not permit us to compare directly the results at Bangalore with those of Kashmere, but the Bangalore results serve to illustrate the working of the method of shower anti-coincidences.

At each location, the following counting rates were measured. Double coincidences I IV and shower anti-coincidences I IV–(II III) were measured with (1) no lead, (2) lead block C_x ($27 \cdot 7$ gm./cm.^{2}) placed above the shower detecting counters at X, (3) lead block C_x at X and lead block B_y (27·4 gm./cm.²) under the shower detecting counters at Y and (4) lead block C_x at X and lead blocks B_y and A_y (26·5 gm./cm.²) at Y. The double coincidence rate II III was also measured without any lead in the apparatus to register the intensity of atmospheric showers. The object of placing C at X was to increase the showers associated with the soft component, and varying amount of lead was placed at Y in order to investigate the absorption of the total intensity as measured by coincidences I IV and the meson intensity as measured by coincidences I IV–(II III). The experimental values of the intensity determined with the various arrangements at different altitudes are given in Table I.

TABLE I

Coincidence Counting Rates per minute	I IV	I IV −(II III)	I IV	I IV −(II III)	I IV	I IV −(II III)	I IV	I IV −(II III)	II III Atmospheric showers
Lead Blocks	..	..	C_x	C_x	C_x+B_y	C_x+B_y	$C_x+B_y+A_y$	$C_x+B_y+A_y$	..
Bangalore 3,000 ft.	2·876 ±·035	2·738 ±·037	2·526 ±·031	2·341 ±·029	2·282 ±·089	2·168 ±·043	2·129 ±·033	2·074 ±·035	29·05 ±·47
Gulmarg 8,900 ft.	4·61 ±·10	4·03 ±·17	3·65 ±·17	2·93 ±·16	3·01 ±·15	2·74 ±·11	2·66 ±·10	2·39 ±·06	52·40 ±1·54
Tronkhal 11,000 ft.	5·24 ±·14	.. ..	4·40 ±·15	4·00 ±·15	3·89 ±·18	3·66 ±·18	3·69 ±·10	3·28 ±·08	66·6 ±1·2
Alpathar 12,800 ft.	5·93 ±·16	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Cosmic Ray Point 13,900 ft.	6·54 ±·20 ..	.. .. ..	5·82 ±·24 ..	4·58 ±·18 ..	5·03 ±·20 ..	4·41 ±·18 ..	4·10 ±·17 ..	4·02 ±·17 ..	78·4 ±2·7 ..

The absorption curves are shown in Fig. 3 for the different altitudes. These curves clearly exhibit that as the electron intensity gets absorbed with increasing lead, the difference between the rates I IV and I IV–(II III) steadily diminishes. The forms of the two curves are also different; for while the slope of the curve I IV appears to increase with diminishing thickness of lead, the slope of the curve I IV–(II III) seems to vary in the opposite direction. On theoretical grounds of decay the curve for the meson intensity should become horizontal for zero thickness of lead absorber, and we have here a striking demonstration of the fact that the intensity measured by shower anti-coincidences refers mainly to mesons only. While we are not justified in taking the value I IV–(II III) without lead as giving the meson intensity for no lead, because the efficiency of excluding electrons by their

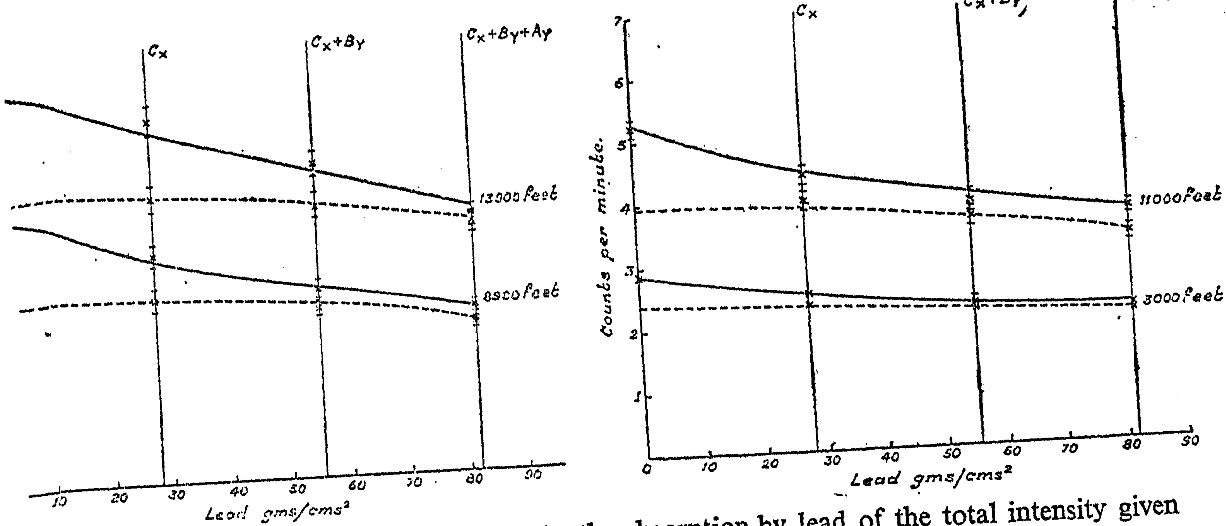


FIG. 3. Graphs showing for various altitudes the absorption by lead of the total intensity given by the counting rates I IV (continuous curves) and the meson intensity given by the counting rates I IV–(II III) (broken curves).

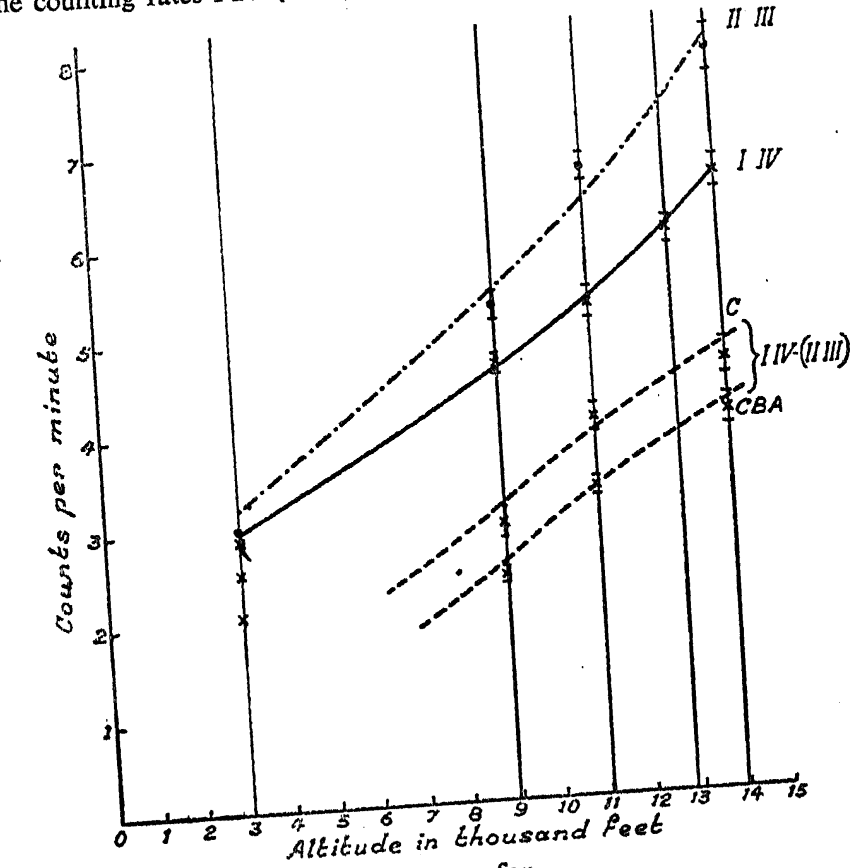


FIG. 4. Graphs showing intensity altitude curves for
(1) Atmospheric shower rate II III,
(2) Total intensity I IV, and
(3) Meson intensity as measured by I IV–(II III) with lead C_x and $C_x+B_y+A_y$.
The Bangalore results have been plotted but are not directly comparable.

howers might be low without the lead block C, we can roughly extrapolate he shower anti-coincidence curve to zero thickness. It is then found that he percentage of mesons in the total cosmic ray intensity diminishes from

79% at 3,000 ft. to a value of 64% at 13,900 ft; but large error may be involved in both these estimates. At the same time however, the percentage of slow mesons in the total meson intensity appears to increase from 11% to about 18%.

The variation of the various counting rates with altitude is plotted in Fig. 4. The variation of the atmospheric shower rate is also given for comparison on the same graph. It is seen that while the total intensity I IV varies in a manner similar to the variation of the atmospheric shower intensity, the meson intensity as measured by the shower anti-coincidences has a flatter slope. The accuracy of the results is not such as to definitely conclude that the variation of the hard and soft components is very different in the region of the atmosphere investigated, but there seems to be little doubt that above 10,000 ft. the total intensity starts to rise more rapidly than the meson intensity. This is indeed in agreement with the results of Jesse *et al.*

4. *Discussion*

Judged by the preliminary results obtained at Kashmere, the method of shower anti-coincidences appears to be fairly satisfactory in giving the meson intensity. The Kashmere readings however suffered from one serious drawback in that only double coincidences were measured with and without shower anti-coincidences. The contribution of side showers to double coincidences can be quite appreciable, as demonstrated by Greisen and Nereson.[11] This contribution would depend among other things on the separation of the two counters measuring the double coincidence rate. In the experiment performed at Bangalore for determining the efficiency of registering shower anti-coincidences, the maximum contribution due to side showers came to 13% of the double coincidence rate assuming 100% efficiency for the two middle counters. The separation of the counters A and D was in that experiment only 14 cm., while the separation of counters I and IV in the Kashmere and Bangalore series was 43 cm. Another point which should be considered before judging the accuracy of the Kashmere results is that while the Kashmere results were obtained with the apparatus in a small tent, the Bangalore experiment was performed in a tiled roof building where the ceiling was about 30 ft. above the apparatus. Taking all these into account, it appears that the contribution of side showers could not be greater than 10% of the double coincidence rate I IV without lead absorbers. The effect of side showers would be independent of the amount of lead placed within the apparatus, and would therefore adversely affect the operation of the shower anti-coincidence arrangement in detecting mesons. This is because the percentage increase due to side showers in the meson intensity would be greater than in the total intensity and this would tend to increase the proportion of mesons.

The Kashmere results can be improved upon by placing a lesser thickness of lead at X than was actually used. The thickness of lead necessary for the maximum of the Rossi curve obtained from triple coincidences I II III would obviously be the ideal thickness to use. It comes to about 1·5 cm. Apart from being most effective in cutting out showers, it will also lower the low energy limit for the measurement of mesons. A further point that emerges is to test the absorption of the meson intensity as measured by shower anti-coincidences in the region of smaller thicknesses of lead absorber in the position Y. An accurate experiment is now in progress where quadruple coincidences are measured along with shower anti-coincidences and a much greater statistical accuracy is aimed at. The results will be shortly published in another communication.

The main defect of the method of shower anti-coincidences for measuring the meson intensity lies in the fact that multiple penetrating particles that are sometimes observed in a Wilson Chamber are also liable to be cut out. In addition, it is possible that knock-on electrons accompanying the mesons might prevent them from being measured. Both these effects would be more pronounced for high energy mesons and may not affect appreciably the intensity of slow mesons. The result of this might be to increase the measured proportion of slow mesons to the total number of mesons. The last and the most obvious possibility of error arises from electrons which may not produce large enough showers so as to be cut out by the shower anti-coincidence arrangement. With the help of a more accurate determination of the meson absorption curve, it is hoped that it would be possible to estimate the errors due to these causes.

One point that emerges from a comparison of the results at Bangalore and Kashmere is that at Bangalore there is a considerable hardening of the radiation. This is clearly seen in Fig. 4 showing the variation of the intensity with altitude, where the Bangalore values are also plotted. Probably the hardening is due to the latitude effect, but some of it might be attributed to causes connected with the different experimental environment at Bangalore. This hardening if confirmed by subsequent more accurate experiments would throw light on interesting questions regarding the origin of the meson component; but it would be too premature to draw any conclusions at present. Another point of interest in the altitude intensity curves is the tendency of the meson intensity curves to become flat with increasing altitude. Here too, little weight can be attached on account of the fact that there are only three points from which the shape of the curve can be judged. However, all these questions indicate the necessity of performing the experiment with greater accuracy and under more rigorous conditions at various altitudes and at different latitudes. This will be shortly undertaken.

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5. *Summary*

A new method of measuring the meson intensity by registering shower anti-coincidences is described. Its special merit lies in bringing for the first time under the field of direct experimental measurements, the slow mesons which are usually cut out in experiments where lead absorbers are used to filter out the soft electron component. The preliminary results obtained with this arrangement at altitudes up to 13,900 ft. in Kashmere are reported. Absorption curves for the meson and the total intensity at various altitudes as well as the altitude intensity curves for the total and the meson component have been given. Improvements in the technique by using fourfold instead of twofold coincidences for measuring the vertical intensity, and the use of optimum thickness of lead for generating the maximum number of showers are suggested.

Some special points of interest which emerge from the altitude intensity curves for mesons have been pointed out, and the need for more accurate measurement is indicated to decide the issues.

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