Effects of Scattering and Absorption of Mesons on Coincidence-Anticoincidence Measurements

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Effects due to absorption and scattering of cosmic-ray mesons with respect to position and nature of various materials were studied with a coincidence-anticoincidence counter. Lead, iron, and paraffin and combinations of them were used. The position of the material was found to account for large variations in the counting rate which could be greater or less than that with no absorber. Effects which had sometimes been previously reported by others to indicate the presence of neutral particles are shown to be largely due to the geometry and other incidental causes. There was, however, a small residual effect due to paraffin, greater than the statistical error, always in the direction which could be interpreted in terms of exchange of charge or the production of neutral rays.

IN a number of earlier experiments by other investigators[1] using coincidence circuits a difference in counting rate was observed upon changing the position of a layer of lead from above to below the upper tube of an array. In 1940 Rossi[1] and others showed that the results of these experiments which had been sometimes interpreted to indicate the presence of incident neutral particles could be explained by such effects as knock-on showers, scattering, and side showers. In a further attempt to detect incoming neutral rays they placed anticoincidence tubes above an array of coincidence tubes. Again the change in counting rate when lead was used as the absorber was given a similar explanation in terms of showers and incidental effects. A more recent report by de Vos and du Toit[2] states that an effect believed to be due to incoming neutral particles in the cosmic rays was obtained by interchanging a thin layer of paraffin from above to below the upper tube of a coincidence counter arrangement. In such a thin layer of paraffin the above effects due to showers, etc., would be expected to be small.

In the present experiments measurements were made with a coincidence-anticoincidence array, the second tube from the top being in anticoincidence.[3] It is shown that considerable variations in counting rate are obtained, due chiefly to absorption and scattering not only when a heavy absorbing layer was moved from below to above a tube but also when it was moved to a different position between two tubes. The effect of paraffin alone was found to be slight. Such absorption and scattering due to heavier materials could easily obscure other lesser effects as, for instance, those possibly due to neutral rays if they were present. Comparison was made of the effects of iron, lead, and paraffin singly and in combination in various positions with respect to the counter tubes. The lead was used because of its high scattering power. Iron was used in order to compare effects of scattering and absorption with lead. Paraffin was used to test the existence of any effect in the heavier materials sensitive to the presence of a light material.

The Geiger-Müller tubes were placed, as indicated in Fig. 1, in a horizontal position, one above the other in a vertical array, and were connected in a conventional Rossi-type circuit with constant voltage regulation. They were 18 in. long, $2\frac{1}{4}$ in. in diameter, and were separated 14 in., 12 in., and 12 in. between centers, starting from the top. The thicknesses of absorbing layers used in all cases were 10, 7, and 3.7 cm of iron, lead, and paraffin, respectively. The positions of the absorbing layers are indicated by the letters A, B, C, and B'. In positions A, B, and C the layers were placed directly above the tubes and were so supported at the ends that no other material intervened between the tubes except in the case of lead which rested upon a comparatively thin iron plate. In position B' the material was raised $5\frac{1}{2}$ in. above tube 3 and was then close to the anticoincidence tube above it. The width of the absorbing layers was such as to just cover the tubes without projecting appreciably at the sides in order to reduce side effects of scattering and absorption to a minimum. The absorbing layer above the array due to the building in which the measurements were made was equivalent to 18 cm of lead. Due to the slow counting rates, observations were carried out over a period of many months. Frequent checks were made of the operation of the counter, and frequent tests were made of the ability to repeat measurements in different positions.

In practice, the counts actually recorded by such a coincidence-anticoincidence counter may be due chiefly to two types of effects: (1) Approximately vertical effects such as a single ray (or its secondaries) passing through all counter tubes but failing to discharge the anti-tube because of faulty alignment; (2) side effects as shower rays, or accidental coincidences (or their secondaries produced in the apparatus) which discharge the coincidence tubes within a period of time less than the resolving time of the circuit.

Various preliminary control measurements made with two, three, and four tubes, both in line and out of line, gave information as to relative counting rates due to

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[1] Rossi, Janossy, Rochester, and Bound, Phys. Rev. **58**, 761 (1940). (See this for list of previous work.)
[2] P. J. G. de Vos and S. J. du Toit, Phys. Rev. **70**, 229 (1946).
[3] The measurements were concluded by Rogers D. Rusk.

vertical and side effects and also of the efficiency of the tubes and circuit. The over-all efficiency was believed to be greater than 99 percent. That the counting rates obtained with the tubes in line as shown in Fig. 1 was approximately the same as when the tubes were moved out of line indicated that most of the counts with no absorbing materials were due to side effects. Any variation in rate in the presence of absorbing layers must hence be interpreted in terms of the geometry of the system. Measurements of the resolving times made by using a radioactive source gave 10^{-3} sec. which indicated that a considerable part of the counts obtained could be accounted for by accidental coincidences directly or indirectly due to side particles.

Measurements were made with various absorbers in different combinations and in different positions. The results are given in Table I. With lead in position C, the effects due to lead, iron, and paraffin were tried in positions A and B. With iron in position A, and lead in position C, the effects of paraffin in positions B and B' were tried. Measurements were made without lead at C in order to detect effects due to soft secondaries as distinguished from penetrating rays. The results are indicated in the table.

When no other absorbers were in position, the presence of the lead layer above the lowest tube (position C) decreased the counting rate a considerable amount from what it was with no absorbers at all. When the lead was moved from position C to position B, a further decrease in the counting rate was obtained. With the absorbing layer of lead in position C and a similar layer of lead added in position B the counting rate was still lower. If most counts were due to side effects, it would appear that the lead in position B or C served in large part to shield either by absorption or scattering the tube below it from soft rays coming from the side. Any increase in counting rate due to showers in the lead was hence either negligible or obscured by the larger effects.

When the lead was placed in position A above the anti-tube instead of below, with no absorber at C, a considerable increase in counting rate was obtained over the rate when no lead was present. This increase could hardly have been due to shower particles from the lead hitting tubes 3 and 4 without passing through the anti-tube because of the size of the lead screen. If many shower particles were produced in the lead above the anti-tube which then traversed the anti-tube, there should have been a diminution in counting rate due to increased deadtime of the anti-tube. However, the lead was of such a thickness as to cut off most of such shower particles due to rays coming in from above. It might be expected that shielding the anti-tube with lead just above it would produce an opposite effect from lead placed just above a coincidence tube if it is true that the material shields the counters from soft side-shower particles and accidentals by absorption. However, the effect was considerably greater than would be expected from a consideration of the resolving time alone.

Rossi, *et al.*,[1] found that the presence of lead directly under the anti-tube increased the counting rate observed in their arrangement. This is in contradiction to the present results obtained with lead at B, however; the geometry of their experimental arrangements was quite different from the above. A further test of the effect of position in the present experiment was made by raising the lead from position B to B'. The counting rate was then observed to increase and be above the value with no lead and in agreement with results observed by Rossi. The increase as observed by Rossi was attributed largely to showers produced in the lead. In the present experiment the difference in counting rate between B and B' seems chiefly due to the fact that in position B the lead acts as a more complete shield of the tube below it, while in position B' the lead shields the lower tube to a much less degree and is itself shielded by the anti-tube above it. Obviously if the difference were due to effects of the first type as mentioned above, the change in position of the lead from B to B' would have little effect. The increase in counts in position B' could hardly be due to showers as suggested, as these should be even more effective when the absorber was in the lower position B. The geometry of the system indicates that, in general, small angle scattering inward would approximately balance small angle scattering outward. A considerable number of additional rays incident at a small angle to the vertical, however, could be scattered out if the angle of scattering were large. If such scattering be taken as the explanation of the decrease in counting rate with lead at B, it would seem necessary to assume a nucleon scattering cross section larger than

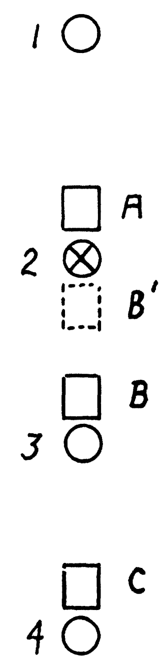

FIG. 1. Arrangement of tubes and absorbers. Tube 2 is in anticoincidence.

TABLE I. Variations in the counting rate for different absorbers in different positions are given in terms of counts per hour and the probable statistical error is indicated. (P = paraffin.)

Positions *A*	*B*	*B'*	*C*	Total counts	Total hours	Count per hr.	Statistical error
—	—	—	—	913	141.7	6.42	±0.21
Pb	—	—	—	1060	114.6	9.25	±0.28
—	Pb	—	—	866	189.9	4.56	±0.16
—	—	Pb	—	594	67.4	8.80	±0.35
—	—	—	Pb	285	53.6	5.31	±0.31
Pb	—	—	Pb	916	173.7	5.27	±0.17
Pb	P	—	Pb	922	161.5	5.70	±0.18
Pb	P	—	—	1374	145.6	9.44	±0.25
—	Pb	—	Pb	583	169.5	3.44	±0.14
Fe	—	—	Pb	1223	288.5	4.23	±0.12
Fe	P	—	Pb	1449	307.5	4.70	±0.12
Fe	—	P	Pb	2039	453.0	4.51	±0.10

10^{-26} cm^2; this may be estimated by application of the formula[4]

$$J = F/tN,$$

where J is the cross section for scattering, N is the number of nucleons per cc, t is the thickness of the absorber, and F is the fraction of rays undergoing large-angle scattering presumably due to other than Coulomb forces. Such a large cross section is not in accord with previous work, which leads to a cross section more nearly of the order of 10^{-28} cm^2 for mesons of spin $\frac{1}{2}$. Hence, it is concluded that the observed diminution in counting rate is chiefly due to screening by absorption. With lead in positions B and C, a rate of 3.44 counts per hour was obtained. An equal weight of iron at B instead of the lead gave a variation of less than the statistical error from this value. The major part of the decrease in counting rate can hence be attributed to absorption. Since the absorptions of the two substances for the thickness used should be approximately the same, any difference between the counting rates could be attributed to scattering but was evidently small.

If a neutral ray were produced in an absorber above the anti-tube by exchange of charge or any other process involving an ionizing ray passing through the first tube, this neutral might pass through the anti-tube and produce an ionizing ray in any material between the counters (or in the material of the counter) and discharge the lower tubes resulting in a count. To test for such an effect, paraffin was placed below the anti-tube while iron was placed above it. Any vertical ray producing ionization in tubes 1, 3, and 4 but not in tube 2 would result in a count. If such counts were due to inefficiency of the tube or circuit they would not be influenced by the presence of an absorbing medium above the anti-tube. Some other process such as exchange of charge resulting in a neutral ray, or production of a photon passing through the next counter, would be influenced by the absorbing material. Such an effect if resulting from a double transition would of course have a low probability. However, when paraffin was used below the anti-tube in position B, the count obtained was always increased more than could be explained by the statistical fluctuations and it was always in the same direction. In order to make a further test of this effect, some evidence of which had been previously reported,[5] a lengthy set of runs was made with paraffin at B, B', and without paraffin. The reduction of the effect when the paraffin was moved up to position B' was too small to warrant the conclusion that the main difference was not due to vertical rays. Since the measurements extended over a considerable period of time, it was believed that any minor fluctuations due to local atmospheric variations would cancel off.

From these experiments, in addition to the effect due to paraffin, it is concluded that the larger part of the observed differences in counting rates is due to absorption of rays coming from the side together with some scattering. These effects vary greatly with the position of the absorber. When such is between an anticoincidence tube it is worth noting that it may produce either an increase or decrease depending on the geometry of the system.

[4] R. P. Shutt, Phys. Rev. **61**, 61 (1942).

[5] R. D. Rusk and A. Rosenbaum, Phys. Rev. **74**, 110 (1948).