EVIDENCE FOR THE PRODUCTION OF MESONS BY NON-IONISING UNSTABLE PARTICLES.

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ABSTRACT.

The investigation on the production of mesons in lead absorbers by non-ionising agents present in cosmic rays carried out by Sirkar and Ghosh (1942) using an anticoincidence circuit has been repeated using a slightly improved arrangement and a counter telescope, first vertical and next inclined to the vertical making an angle of 30° to the east. It has been observed that the numbers of non-ionising agents producing mesons in a lead absorber 5 cm. thick are about 4·4% and 5·2% respectively of the total number of mesons in the vertical and inclined directions recorded by the threefold coincidence system forming the part of the anticoincidence system. With a lead absorber 10 cm. thick placed above the counter telescope the said numbers reduce to 1·4% and 1·35% respectively. The absorption of this filtered component in lead is observed to be less than that of mesons. From these results it has been concluded that these non-ionising agents are unstable and have a life of the same order as that of the meson.

1. INTRODUCTION.

Though it has been definitely established that mesons are secondary particles produced by some primary agents in the atmosphere the exact mechanism of such a production has not yet been clearly understood. Several hypotheses have been put forward regarding the production of mesons. According to Heitler (1938), Bhabha (1938) and others mesons may be produced by energetic photons, the probable reactions being given by

$$h\nu+p \rightarrow n+m^+$$
$$h\nu+n \rightarrow p+m^-$$

where p, n, m^+ and m^- denote proton, neutron and positive and negative meson respectively. The value of $h\nu$ should be larger than 10^8 e.v. This hypothesis cannot explain the excess of positive mesons over negative mesons deduced from the observed east-west asymmetry. Johnson (1939) put forward the hypothesis that mesons are produced by protons according to the following schemes:

$$p+p \rightarrow p+n+m^+$$
$$p+n \rightarrow p+p+m^-$$
$$p+n \rightarrow n+n+m^+$$

Carlson and Schein (1941) proposed that a proton might produce by some unknown mechanism n mesons at a time; the value of n may be up to 8 or 10 (Swann, 1940). A quantitative theory for the production of mesons by photons and charged particles has also been put forward by Booth and Wilson (1940*a*). Again Nordheim (1939*a*) pointed out that part of mesons might also be produced by some non-ionising primary agents other than photons.

The existence of neutral mesons has been postulated in the theory of nuclear forces by Yukawa and Sakata (1937). The scattering of such particles as well as their interaction with matter have been dealt with theoretically by Booth and Wilson (1940*b*) and by Bhabha and Rao (1941). As regards the experimental evidence for the existence of such particles, Arley and Heitler (1938) first pointed out that the increase in the number

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of coincidences observed with the shift of the absorber from its position between the two counters to the top of the vertical counter telescope formed by the two counters might probably be due to the production of mesons in the absorber by 'neutrettos'—a name given by them to neutral heavy particles. The reaction proposed by them are as follows:

$$m^0+n \rightleftarrows p+m^-$$
$$m^0+p \rightleftarrows n+m^+$$

m^0 denoting the neutral meson or neutretto. Various hypotheses have been put forward regarding the stability of such a particle. According to Nordheim (1939*b*) neutral mesons are stable and disappear only after collision with matter. Sakata and Tanikawa (1940) have pointed out, however, that neutral mesons might be unstable and the life might be of the order of 10^{-16} seconds.

Various attempts have been made in recent years to investigate the production of mesons by non-ionising agents other than photons present in cosmic rays. Rossi, Janossy, Rochester and Bound (1940) have subsequently carried out some investigations and criticised the results obtained previously by other workers. They concluded that at sea-level mesons are not produced in any appreciable quantity in a lead absorber by penetrating non-ionising agents in cosmic rays and according to them the positive results reported by previous workers might be due to some spurious phenomena such as side-showers. This has been discussed by Sirkar and Ghosh (1942). Rossi and Regener (1941) have, however, reported positive results at an altitude of 4300 m. above sea-level where they found that about 1% of the total meson intensity was produced by non-ionising rays other than photons. These penetrating rays according to them might be neutrettos or very high energy neutrons which are fairly abundant at higher altitudes (Korff, 1940). On the other hand, Sirkar and Ghosh (1942) at Calcutta (sea-level) using an anticoincidence circuit observed that about 2% of the total meson intensity was produced by non-ionising rays other than photons in a lead absorber 5 cm. thick. They also pointed out that in the circuit used by Rossi *et al.* (1940) at sea-level, the charged particles scattered by the absorber and passing through the topmost counter might probably vitiate the results obtained by them, while in the anticoincidence circuit used by Sirkar and Ghosh these scattered particles would not register any count.

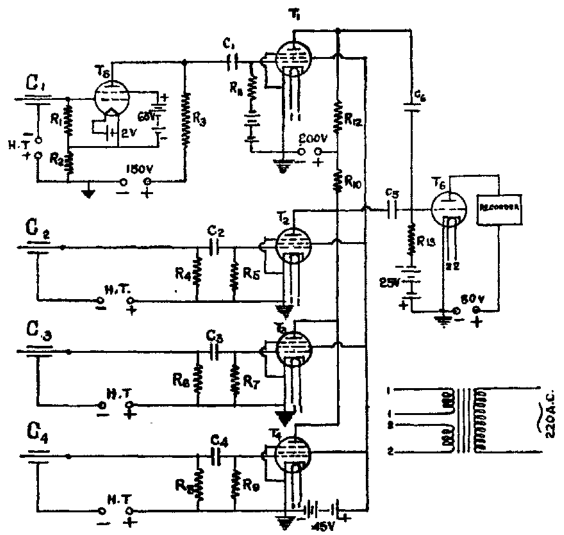
In the experiment of Sirkar and Ghosh the background effect in their anticoincidence arrangement was rather large, being about 9% of the total meson intensity. This was not quite satisfactory, hence it was thought worth while to repeat these investigations with an arrangement in which the background effect was reduced considerably. It was further thought advisable to investigate the phenomenon in two directions, viz., one in the vertical and the other making an acute angle with the vertical, so that the results might give more information regarding the stability or instability of the non-ionising particles.

The results of these investigations were reported briefly last year (Sirkar and Bhattacharyya, 1942). An investigation about the presence of neutral particles in cosmic rays at sea-level was carried out, however, almost simultaneously by Janossy and Rochester (1941) but the results obtained by them were not known to the present authors when the preliminary report of the results of the present investigation was published. All these results have been compared and discussed in the present paper. The same problem was also investigated by Nishina, Birus, Sekido and Miyazaki (1941) and by Nishina and Birus (1941) but not with any anticoincidence circuit.

2. Experimental Technique.

The anticoincidence circuit used in the present investigation was very similar to that used by Sirkar and Ghosh (1942) with some minor modifications. The diagram of the circuit with proper circuit constants is shown in fig. 1. The working principle of the circuit has already been explained by Sirkar and Ghosh (1942). The counters C_2,

C_3, C_4 form a threefold coincidence counter telescope and C_1 forms the anticounter. The negative pulse through the capacity c_6 was made sufficiently larger than the positive through c_5 by proper choice of resistances R_1, R_{11}, R_{12}, and the grid bias on T_1. Thus the arrangement permits only threefold coincidences to be recorded and the fourfold, twofold coincidences or single discharges do not energise the recorder at all.



$C_1 = C_2 = C_3 = C_4 = \cdot 00015\,\mu F$ $C_5 = C_6 = \cdot 001\,\mu F$.
$R_2 = R_3 = R_{11} = 1\,M\Omega$ $R_1 = 10\,M\Omega$ $R_{13} = \cdot 04\,M\Omega$
$R_4 = R_5 = R_6 = R_7 = R_8 = R_9 = R_{12} = 2\,M\Omega$
T_1 = RCA 32. $R_{10} = \cdot 5\,M\Omega$
T_5 = G T1 C. $T_1 = T_2 = T_3 = T_4$ = R C.A. 57.
$C_1 = C_2 = C_3 = C_4$ = G-M counters.

FIG. 1. Anticoincidence circuit.

The Geiger-Müller counters used in the present investigation were all prepared in the Palit Laboratory. The efficiency of the counters for charged particles was found to lie between 98·8 and 99·75%. The efficiency of the anticoincidence arrangement was determined by the method suggested by Herzog (1940). The efficiency was found to be more than 99·5%. The resolving time of the circuit was $1{\cdot}22 \times 10^{-4}$ seconds.

3. Experimental Details.

The arrangement of the counters as used in the present investigation is shown in fig. 2. The counter battery C_1 consists of three counters in parallel and forms the anti-counter. Similarly, the counter battery C_4 consists of two counters in parallel placed one above the other such that the total width is about one and a half times that of a single counter. C_2 is a counter of the same diameter as others but of smaller length. As shown in fig. 2 by dotted lines, the topmost counter battery covers the solid angle formed by the four lower counters. Hence a charged particle traversing through $C_2C_3C_4$ must also pass through C_1 and as a result the recorder would not register any count. Though the counters forming the system C_1 were most efficient of all the counters, owing to the small inefficiency of the anticoincidence circuit, however, there was always some background effect. The background effect might also be partially caused by scattering and by showers coming from the sides which discharge $C_2C_3C_4$ without striking C_1.

Ten centimetres of lead were permanently placed at R_1 between C_3 and C_4 to filter out the soft component. A lead block 5 cm. thick was first placed at R_2 to obtain the

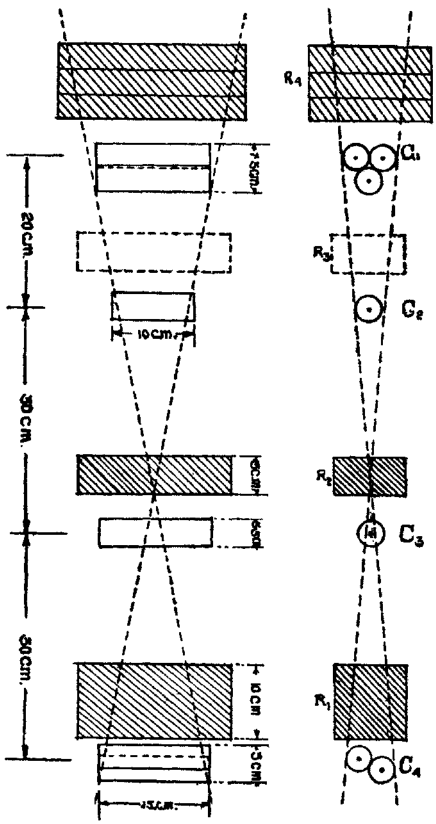


FIG. 2. Arrangement of counters and lead absorbers.

background counts and then shifted to the position R_3 between C_1 and C_2. In the latter position of the absorber, in addition to the background counts, counts would be registered only when non-ionising agents passing through C_1 produced at R_3 ionising particles which could penetrate 10 cm. lead at R_1. The results are given in Table I. The whole system of counters and absorbers was mounted in a panel in such a way that the counter telescope could be made either vertical or inclined at a desired angle to the vertical.

The absorption of the primary neutral particles was investigated by placing various thicknesses of lead blocks at R_4 above all the counters. The results are given in Table II. The absorption coefficient was calculated to be $2{\cdot}3\times10^{-3}$ cm^{-1} lead which is of the same order as that of mesons ($8{\cdot}1\times10^{-3}$ cm^{-1} lead).

In order to investigate whether the anticoincidences are produced by side-showers, the counter C_2 was shifted horizontally through a small distance, so that $C_2C_3C_4$ no longer formed a counter telescope. The absorber of 5 cm. thickness was first placed at R_2 between C_2 and C_3 and the number of anticoincidences in about 60 hrs. was noted. Next, this was placed at R_3 between C_1 and C_2 and the number of anticoincidences was again noted for about the same time. It was observed that the number of anticoincidences did not increase with the shift of the absorber. Thus it was proved that the side-showers did not affect the results obtained in the present investigation.

TABLE I.

Production of mesons in the vertical and inclined directions.

$R_1 = 10$ cm.

Zenith angle.	Nature of coincidences.	Disposition of lead absorber.	Total time in hours T.	Total counts N.	Counts per hour $\frac{N}{T} \pm \frac{\cdot 68\sqrt{N}}{T}$.
0°	$C_2C_3C_4$	$R_2 = 5$ cm. $R_3 = 0$ $R_4 = 0$	15	228	$15 \cdot 2 \pm \cdot 68$
	$C_2C_3C_4 - C_1$	$R_2 = 5$ cm. $R_3 = 0$ $R_4 = 0$	128	80	$\cdot 625 \pm \cdot 048$
	,,	$R_2 = 0$ cm. $R_3 = 5$ $R_4 = 0$	132	170	$1 \cdot 288 \pm \cdot 067$
	,,	$R_2 = 0$ cm. $R_3 = 5$ $R_4 = 10$	105	88	$\cdot 838 \pm \cdot 069$
30°E	$C_2C_3C_4$	$R_2 = 5$ cm. $R_3 = 0$ $R_4 = 0$	20	210	$10 \cdot 5 \pm \cdot 493$
	$C_2C_3C_4 - C_1$	$R_2 = 5$ cm. $R_3 = 0$ $R_4 = 0$	138	80	$\cdot 58 \pm \cdot 044$
	,,	$R_2 = 0$ cm. $R_3 = 5$ $R_4 = 0$	128	144	$1 \cdot 125 \pm \cdot 064$
	,,	$R_2 = 0$ cm. $R_3 = 5$ $R_4 = 10$	115	83	$\cdot 722 \pm \cdot 062$

TABLE II.

Absorption of neutral component producing mesons.

Background counts $= \cdot 625 \pm \cdot 048$ per hour.

$R_3 = 5$ cm. $R_2 = 0$. $R_1 = 10$ cm.

Lead absorber R_4.	Total time in hours.	Total number of anticoincidences.	Counts per hour $C_2C_3C_4 - C_1$.	Counts per hour $C_2C_3C_4$.
0	132	170	$1 \cdot 288 \pm \cdot 067$	$23 \cdot 88 \pm \cdot 83$
5 cm.	100	97	$\cdot 97 \pm \cdot 066$	$19 \cdot 75 \pm \cdot 75$
10 cm.	105	88	$\cdot 838 \pm \cdot 069$	$18 \cdot 06 \pm \cdot 72$
20 cm.	102	84	$\cdot 824 \pm \cdot 061$	$16 \cdot 35 \pm \cdot 62$
30 cm.	110	88	$\cdot 800 \pm \cdot 058$	..

Absorption coefficient $= 2 \cdot 3 \times 10^{-3}$ cm^{-1} lead.

To see whether the neutral radiation producing mesons are really stable, the relative positions of the counters in the counter telescope were fixed and the frame as a whole containing the counters and the lead blocks was made inclined through an angle of 30° to the vertical towards the east, the axes of the counters pointing in the north-south direction as is shown diagrammatically in fig. 3. The whole procedure for the vertical telescope was then repeated with the counter telescope in the inclined direction. The results are given in Table I.

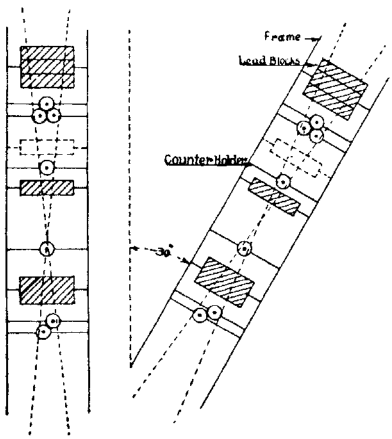


FIG. 3. Arrangement of counters in the vertical and inclined directions.

4. DISCUSSIONS.

The results given in Table I show that, on shifting the lead absorber 5 cm. thick from R_2 to R_3, the number of anticoincidences increases from ·625±·048 to 1·288±·067, i.e. by ·663±·082 without additional lead absorber at R_4 and by ·213±·084 with a lead absorber of 10 cm. thick at R_4. This shows that the number of mesons produced by the non-ionising component is about 4·36% of the total number at sea-level of which only about 1·4% is due to some non-ionising agents other than photons. These may be identified, as will be seen presently, with neutral mesons. It is also evident from Table I that in the vertical direction about 1·4% of the mesons are produced by neutral penetrating particles in the lead absorber while in the inclined direction making an angle of 30° to the zenith towards the east, the number of mesons thus produced is about 1·35% of the total number in the said direction. As the meson intensity diminishes from 15·2±·68 per hour in the vertical direction to 10·5±·49 per hour in the inclined direction, the number of mesons produced by neutral particles also decreases from ·213±·084 to ·142±·076 per hour.

Thus it may be remarked that as the number of mesons decreases in the ratio of about 2·9:2 the number of neutral particles also diminishes in practically the same ratio of·3:2. The diminution of the intensity of the neutral particles in the inclined direction may be partially due to the absorption in the excess mass of air in the inclined direction, but as it has been found experimentally that the absorption of the mesons is of the same order as that of neutral particles, we cannot but infer that the neutral component producing mesons consists of particles which are unstable, and have a life at least of the same order of magnitude as that of mesons. According to Nordheim (1939*a*) neutral mesons are probably stable but according to Sakata and Tanikawa (1940) they are unstable having an extremely short life of the order of 10^{-16} seconds. None of these predictions is, however, proved to be correct by the results of the present investigation, which on the contrary show that if the neutral particles producing mesons are identified with neutrettos, these neutrettos are unstable having a life of the order of a few microseconds.

The instability of the neutral particles producing mesons and the particular value of their life can reconcile the results obtained in the present investigation with those observed by others in similar investigations at higher altitudes. Rossi and Regener (1941) at an altitude of 4,300 metres above sea-level observed that the number of mesons produced by neutral particles is about 1% of the total meson intensity while Schein, Wollan and Groetzinger (1941) in their investigation at an altitude of 9,300 metres (substratosphere) observed that the same number is not greater than 5% of the total meson intensity at that altitude. Also according to the latter authors photons are the main agent of the non-ionising radiations producing mesons. Thus it appears from these results that the number of neutral particles producing charged mesons in a lead absorber, when expressed as a percentage of the total number of mesons, does not increase much with the altitude. As we go higher up, the number of mesons as well as that of the neutral particles producing mesons increase, but their ratio remains practically the same at all altitudes. This observed fact is not an anomaly as the results of the present investigation show that the neutral particles have a life almost equal to that of mesons and therefore the ratio of the number of these particles to that of mesons is expected to remain almost constant at all altitudes. Lastly, the instability and life of neutral particles producing mesons indicate that probably these neutral particles are to be identified with neutrettos and not with neutrons, because it is very unlikely that the neutrons will have a life of the order of that of mesons.

It may be mentioned here that Janossy and Rochester (1941) using a shielded vertical counter telescope and anticoincidence arrangement observed that the neutral particles producing mesons in the lead absorber is about ·04% of the meson intensity at Manchester. They have identified these particles with neutrons. The difference between the present arrangement and that used by Janossy and Rochester is that in the latter arrangement there were extra anti-counters on all sides of the coincidence counters to prevent any charged particle from striking these counters from sides and the absorber was placed permanently at R_3 instead of being shifted from R_2 to R_3. As the effect of side-showers was investigated in the present case and found to be negligible, it is difficult to understand why the results of the present investigation differ from those of Janossy and Rochester. Further, any spurious anticoincidence counts would not diminish proportionately with the meson intensity in the inclined direction. It is not possible at this stage to put forward any hypothesis according to which these results would depend on the locality at which the experiment is performed, but it is difficult to find any reason for which the results obtained in the present investigation can be treated as spurious.

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