45

CLOUD CHAMBER ANALYSIS OF COSMIC-RAY SHOWERS UNDER 10 TO 23 cm. OF LEAD.

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Plate XI

ABSTRACT. A counter-controlled cloud chamber study of different types of showers in Pb, under 10 to 23 cm. has been made to investigate the controversial existence of higher maximum in Rossi curve and its probable origin. The chamber and the counters in triple coincidence were specially arranged to detect the formation of a charged pair or particle by the decay or dissociation of an unstable neutral particle in air under the Pb absorber. The triple coincidence frequency rises by about 28% over the background under about 16 cm. of Pb. Analysis of the shower photographs, however, shows that this rise is largely due to a single charged particle mostly mesons coming from the top absorber which by subsequent knock-on process or otherwise produces the triple coincidence. These singles may account for about 12% of the total rise. About 10% of the total rise may be attributed to mixed meson and meson showers.

Analysis of shower photographs by neutral component shows that out of about thousand photographs we have obtained only one penetrating pair with its apex in air under 16 cm. of Pb and this may be due to a V-type of decay. But we have obtained many other photographs mainly under 15 to 20 cm. of Pb which show isolated pairs of very low energy (inferred from range and angular divergence) formed by a neutral component. These type of showers may account for the remaining 6 to 8% of the total rise at the second maximum. The origin of such pairs particularly in some photographs, by photon or indirectly by neutron is not very clear. There is a third possibility that these pairs are produced by the decay of a neutral particle of very low mass. This possibility may further be checked by a multiple plate chamber as we propose to do.

INTRODUCTION

The aim of this investigation has been to clarify the long persisting controversy over the existence of higher maximum in Rossi curve and to identify the radiation and the mechanism that might contribute to the formation of such a maximum. The senior author (1951) previously reported the existence of a second maximum like many other workers e.g. Clay (1949), Bothe (1950), Kameda and Miura (1950) and others, although some other workers denied its existence. A reference to all the earlier works may be found in the literature referred to above. The old controversy is still persisting and when the present investigation was completed we came across the abstracts of some papers of Bothe and his coworkers (1955) where they report that the previously reported sharp second maximum by them might be due to some defect in the electronics of the complicated circuits used by them. Negative results have also been reported by Pfotzer (1955). Harding (1955) reported a definite rise in the shower frequency by about 3% in the region of second maximum under certain experimental conditions. But McCusker and others (1955) detected a rise by about 2% using counters only but failed to detect any appreciable maximum by the cloud chamber investigation. Choudhury *et al* (1955) have reported a sharp second maximum.

In the previous analysis the senior author came to the conclusion that some of these controversies might be due to differences in geometrical arrangements. In some of the arrangements it seems to the author that there was a greater possibility of the second maximum being masked by oblique showers in the extended absorber or by the side showers coming not through the absorber. Whereas the failure of some recent workers, as for instance, McCusker and others (1955) to find an appreciable second maximum might be due to their experimental arrangements being biased for detecting penetrating secondary radiations only, as the lower tray of counters was covered with 10 to 2.5 cm. of lead absorber. The senior author (1951) from various considerations came to the conclusion that this maximum might be due to the formation of a new unstable neutral particle which subsequently decays or dissociates into a pair of very low energy content. Bothe (1953) and Pfotzer (1953) also previously came to the conclusion that it is necessary to postulate the existence of a new type of unstable particle to explain this maximum and Bothe (1954) afterwards suggested that this new particle might be simply a neutral V-particle formed in the absorber.

In view of all these the present cloud chamber investigation was undertaken to test the various suggestions mentioned above or to identify if any other agency and mechanism are the origin of this second maximum.

EXPERIMENTAL ARRANGEMENTS

An automatic controlled Wilson chamber of Blackett's (1934) model was set up with the modification that the matellic piston in the back chamber was replaced by a rubber diaphragm which was found to give a much better type of sharp tracks. The front chamber is of diameter 1′ and depth 3½″. A 2.5 cm. thick lead plate is placed at its centre to identify the penetrating and the soft component. Following the accepted custom, a particle which passes through this plate without multiplication is considered to be a penetrating one, like meson etc. The chamber was filled with argon. Alcohol with water in the ratio of 75 : 25 was used as the condensant. In order to avoid any complexity due to electronics, oblique showers etc., we used the simplest arrangement of three counters in coincidence and therefore the coincidence frequency is much smaller in comparison with others. In order to detect if there be the formation of any neutral unstable particle in the absorber which after leaving the absorber decays or dissociates in air; the two counters, separated by a distance of about 2 cm., were placed below the lead absorber at a distance of about 70 cm. from it and the cloud chamber was placed immediately above the two counters. The third counter was placed just a little above the cloud chamber. The counters were of dimensions about 20 cm. length and 3 cm. diameter. The lead absorbers used in this experiment are sheets of chemically pure lead and of dimension 1′×1′×1/8″. Stereoscopic photographs were taken with a camera of two lenses. The actual experimental arrangements are shown in the figure 1. The present experiment was set up in the ground floor of a three-storied building, e.g. Baker Laboratory, Presidency College, Calcutta, whereas the previous investigation by the senior author was done in open air.

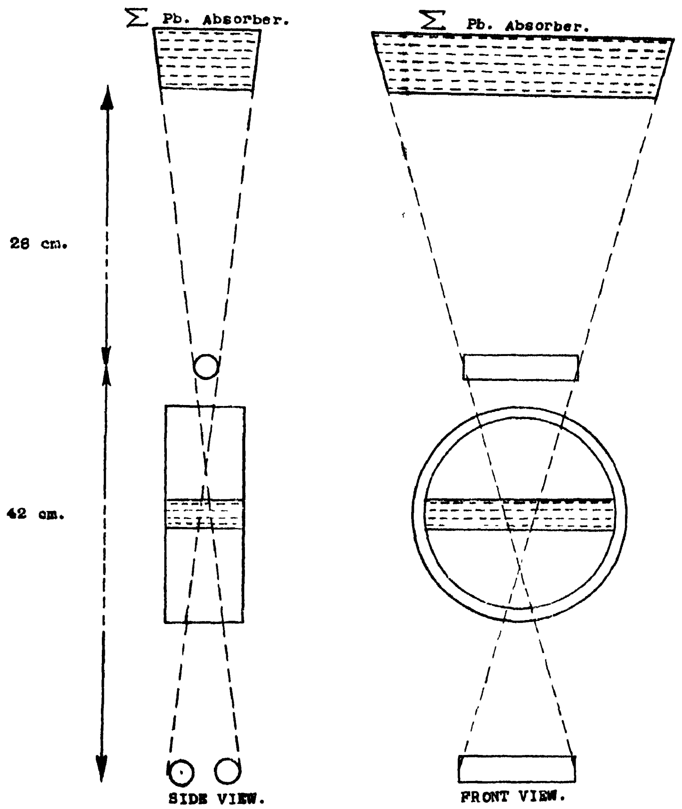

Fig. 1. Experimental arrangements.

EXPERIMENTAL RESULTS

The main experimental results and the analysis of the shower photographs are shown in Table I. By single shower, two-particles shower and more than two particles shower as are given under different columns in Table I, we mean the corresponding number of ionising particles entering the chamber from the top absorber. A single can produce a triple coincidence either by cascade multiplication in the inner lead plate if it is an electron or by knock-on electrons from the inner lead plate or from the lower chamber wall if it is a meson. A single ionising particle can also produce triple coincidence if it be associated with a neutral component e.g. a photon or an unstable particle which afterwards produces more charged particles. A photon can produce charged particles either by Compton process or by a pair formation and an unstable neutral particle can produce a charged pair by decay or dissociation. Many photographs are obtained by us where a single charged particle is associated with another pair of very low energy content mostly produced just at the botton of the inner lead plate and sometimes in air. Typical photograph is shown in the photograph No. 2 (Plate XI) obtained under 16 cm. of lead. We have also obtained many cases of such isolated pair formation without association of any charged particle. These are given under a separate column in Table I. A typical photograph is shown in photograph No. 3 under 16 cm. of lead which shows simultaneous production of two such pairs.

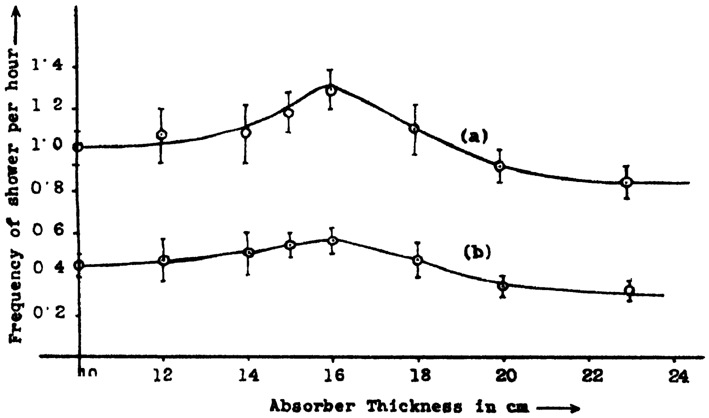

Fig. 2. (*a*) Total shower frequency curve.
(*b*) Single frequency curve.

We have plotted the total shower frequency against the corresponding absorber thickness in figure 2 (Curve *a*). We have also plotted the frequency of singles in figure 2 (Curve *b*). The results given in Table I as well as both the transition curves show a maximum under about 16 cm. of lead absorber. The rise in the total shower frequency under 16 cm. lead is about 28% higher that that under 10 cm. of lead. Such difference is much beyond the standard error. For statistical significance of the results we particularly concentrated our observations under 10, 15, 16, 20 and 23 cm. of lead. Again to check any periodic or abrupt variation of total cosmic ray intensity we measured coincidence rates under each thickness in two different periods showing the same results with minor variations. The frequency of two particle-shower does not show any significant increase in the region of second maximum but the frequency of more than two-particle shower shows an increase in the region under 16 to 20 cm. of lead though the standard deviation is fairly large. We have also obtained some blank photographs which under 16 cm. of lead is about 15% of the total number of photographs and the percentage of blanks under other thicknesses of absorber also do not significantly vary from this. In view of the geometrical arrangement of the counters and the limited depth of focus of the camera etc. such a percentage of blanks may be quite reasonable.

For further analysis the showers of at least two particles containing one meson, two or more mesons are shown separately in Table II. As most of the penetrating particles are mesons, we have classified them as meson associated showers. Their respective frequences are also given. The frequency of meson shower containing at least two mesons are separately given under the last column in Table II. The total frequency of meson associated shower as well as that of meson shower are separately plotted, in figure 3. against the corresponding absorber

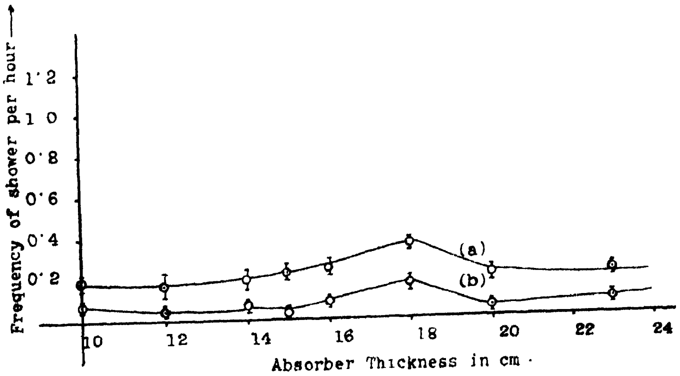

Fig. 3. (*a*) Meson associated shower frequency curve.
(*b*) Frequency of two or more meson associated showers.

thicknesses of lead. Though the shower frequency is very small in comparison with the total shower frequency still the meson associated shower shows a distinct rise in the region under 16 to 18 cm. of lead. The meson shower frequency shows an abrupt rise under 18 cm. of lead. Such abrupt rise may be accidental or the penetrating particles may be either very short-lived or their energy is very small so that these are easily lost by decay, scattering or absorption. Some typical photographs of meson shower are also shown in the photograph No.4 and No. 5. (Plate XI) The photograph No. 4 obtained under 16 cm. of lead shows the tracks of 4 mesons whereas the photograph No. 5 under 20 cm. of lead shows the tracks of about 6 mesons. These two may be pure penetrating showers.

A few bursts and nuclear interactions have also been photographed all in the neighbourhood of second maximum under 15 to 20 cm. of lead. Typical photographs are shown in the photographs No. 6, 7 and 8. Photograph No. 6 obtained under 18 cm. of lead shows at least one meson associated with a nucleonic pair (to the exteme left) produced by a neutral particle in the inner lead plate. Photograph No. 7 obtained under 15 cm. of lead shows a shower which may be a star produced by a neutral radiation. Photograph No. 8 obtained under 20 cm. of lead shows a burst of probably hundreds of particles. In this connection a reference may be made to the workers of Mohr and Stafford (1944) who obtained a hump using an ionisation chamber under about 20 cm. of lead. Also Schöpper, Höcker and Kuhn (1951) using photographic emulsion have obtained a second maximum starting from 15 upto 24 cm. of lead.

DISCUSSION ON THE PROBABLE ORIGIN OF SECOND MAXIMUM

The above analysis of the shower photographs shows that the meson associated shower and meson shower may only account for an increase in the shower frequency by less than 10% of the total rise which is about 28% in the region of second maximum. But the frequency of singles, which is about 50% of the total frequency, shows a definite maximum coincident with that of the total frequency. It appears therefore that the showers with single observable charged particles from the top absorber largely contribute to the origin of the second maximum and may account for about 12% of the total rise. An analysis of the singles together with the triple coincidences produced by neutral component under different thicknesses of lead absorber are given in the Table III which shows that majorities of these are either simple meson or meson which has produced knock-on showers in the inner lead plate. A few of these have produced cascade but another appreciable fraction shows singles associated with another pair of very low energy content. The simple mesons which have not produced any knock-on shower in the inner lead plate may also be associated with a non-ionising component which can generate a charged particle or a charged pair as in the previous case to produce triple coincidence. The possibility of a knock-on shower from the thin glasswall of the chamber is very small. Clay (1949) and his co-workers suggested that the second maximum may be due to knock-on showers by a meson. The maximum occurs when the rate of accumulation of the soft component by knock-on process is just equal to the rate of absorption of this component. But Pfotzer (1953) showed that such a mechanism can produce a maximum under much lower thickness of the absorber e.g. about 4 cm. of lead. Harding (1955) very recently suggested that the second maximum may be due to mesons of sharp range about 18 cm. of lead which stopping in the ground immediately below the lower

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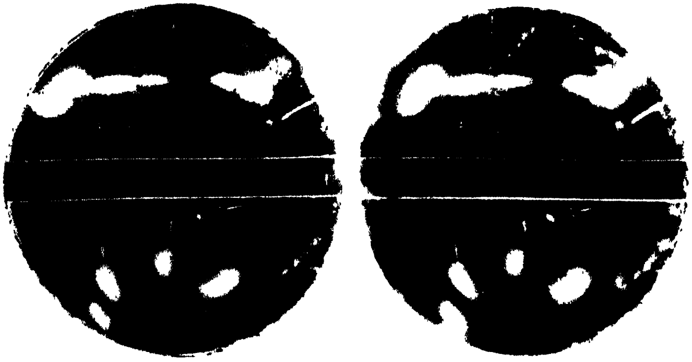

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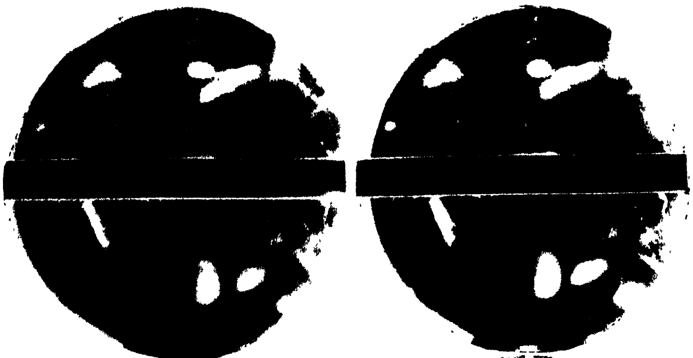

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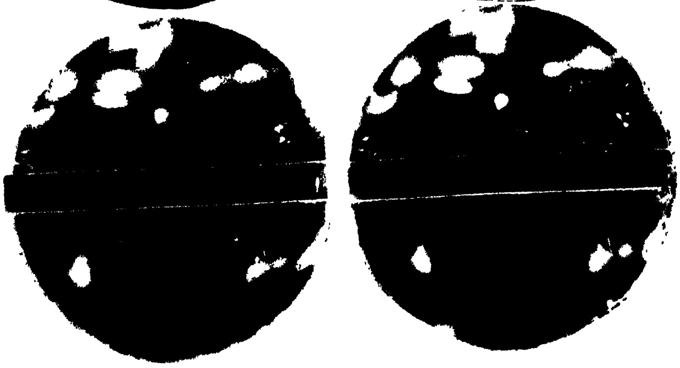
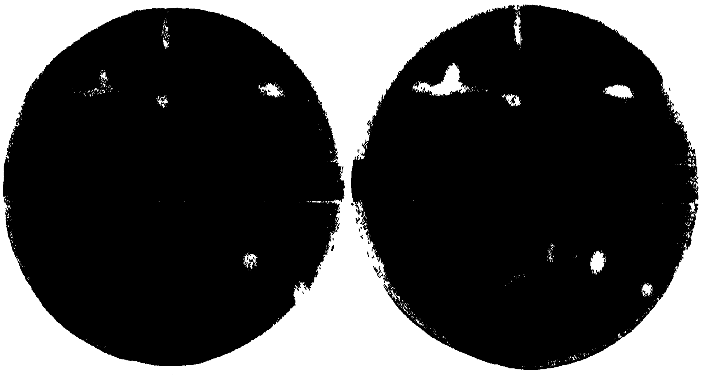


Typical shower photographs.

5.



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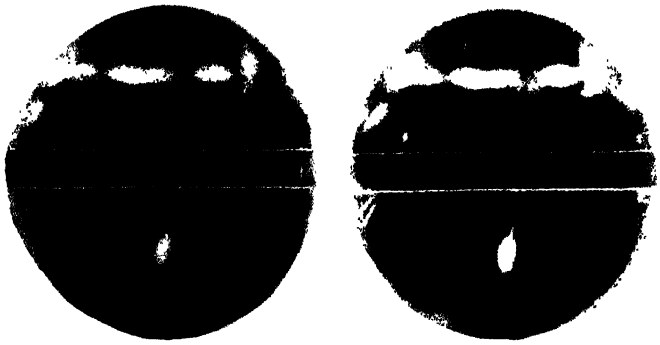

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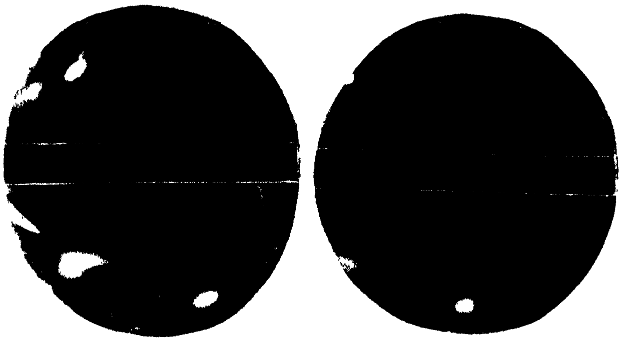

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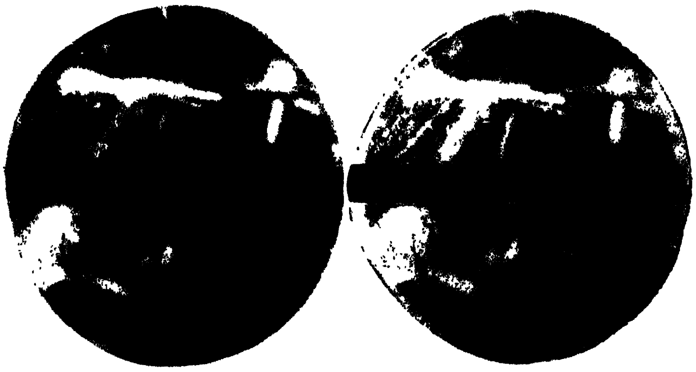

Typical shower photographs.

counter tray emit decay electrons in the upward direction. Our chamber was about $1\frac{1}{2}'$ above the ground but we have not detected any such decay electron either entering the chamber from below or generating any shower in the inner lead plate. In the energy spectrum of meson at sea level also it is not known that there is a sharp peak in the region of second maximum.

Kameda and Miura (1950) obtained a very sharp second maximum which they inferred to be produced by the nucleonic component from the absorption mean free path of the primary rays. Hayakawa and Nishimura (1950) from a theoretical analysis of the results of the previous authors concluded that the second maximum consists of the overlapping of two kinds of secondary ionising particles. One type of secondaries have a definite range of about 16 cm. of lead whereas the other type has much longer range. They also further conclude that the sharp secondary maximum obtained by Kameda and Miura are due to the solid angle subtended by their counter train being very small and consequently the ratio J_N/J_E i.e. the vertical intensity ratio of the nucleonic component to the soft component, is much larger than that of the wide angle primaries. For wide angle primaries, the tail of the cascade shower and the back-ground knock-on electrons would mask the second maximum. In our arrangements also since the lower counters were placed at a distance of about 70 cm. below the absorber the solid angle is very small but our results, though show a maximum due to penetrating components, can account for less than 10% of the total rise under second maximum. In this connection a reference may also be made to the work of George (1947) and others who reported a maximum of penetrating showers under about 15 cm. of lead. The secondaries are of range of about 50 cm. of lead. Walker (1950) also pointed out that the penetrating showers have two kinds of secondaries of ranges of about 15 cm. of lead and 1 cm. of lead.

Bothe and Schemeiser (1938) originally suggested that the second maximum might be due to narrow meson pairs. But in our investigation out of more than one thousand photographs we have obtained only one such narrow pair under 23 cm. of lead. Similarly we have obtained only one photograph, No. 1, under 16 cm. of lead which shows a pair of penetrating particle with its apex in air or just on the top counter above the cloud chamber. Such a pair may be produced by V-type of decay of a hyparon e g. $V^0 \rightarrow P + \pi + Q$. $Q = 37$Mev; but its frequency is so small that such V-particles cannot give rise to the second maximum. Again considering the probable contribution to second maximum due to neutral component, as shown in Table III, we have obtained many photographs which show isolated pairs of very low energy content (indicated by the angle of emission and the range in the chamber) either associated with another single soft ionising particle or without any such ionising particle We have also some soft ionising particles absorbed in the inner lead plate. For triple coincidence such particles must be associated with other soft neutral component. These cases are represented under the last five columns of Table III together with the frequency of such showers under different thicknesses and though the statistical error is large the results show a definite increase of this type of shower under 15 to 20 cm. of lead in comparison to that under 10 and 23 cm. of Pb. The abundance of these showers is such that it may contribute 7 to 8% rise to the total shower frequency at the second maximum. Again whenever we observe such a pair (mostly absorbed in the chamber gas) there must be simultaneous formation of other such pairs to produce triple coincidences and as such their probability of detection is much smaller than the total triple coincidences that may be produced by a single such pair associated with a charged particle.

Now to explain the formation of such soft component particularly the soft pairs by neutral component under 15 to 20 cm. of Pb, there are three possibilities i.g. (1) pair formation by a photon below critical energy present in the tail of the cascades as shown by Greisen and others (1948),(2) pair formation by photon originating from neutron capture or inelastic scattering of neutron in Pb and (3) pair formation by the decay or dissociation of a new unstable neutral particle of very low mass. But the photons below the critical energy are rapidly absorbed in Pb and as such these cannot explain the increase or even the steady value of such shower frequency in the region from 15 to 20 cm. of Pb. Similarly the increase of such shower frequency may not be due to neutron component as the neutron transition curve in Pb investigated by Tongiorgi (1949) does not show any increase in the region under investigation. So there remains the third alternative in support of which the typical photographs No. 3 obtained under 16 cm. of Pb may be significant. The photograph shows simultaneous formation of two such pairs just at the bottom of the inner Pb plate without any appreciable Compton electron or cascade shower in the chamber. From the angle of the emission it appears that the energy of the photons (if photons are supposed to be the origin of these pairs) is near to 1 Mev. only. As such, the probability of pair formation by such photon is much smaller in comparison with that of Compton scattering. Moreover, the formation of two such simultaneous pairs is highly improbable. If these pairs are produced by the decay of a new unstable particle its rest mass must also be very small. In this connection reference may be made to the previous works of the senior author (1951, 1954) on anomolous gamma-ray absorption where also the possible existence of such a particle was suspected.

In the light of the above analysis of the results we are undertaking a further investigation with a multiple-plate cloud chamber to check the probable formation of such a new unstable particle.

ACKNOWLEDGMENTS

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