PHYSICAL REVIEW VOLUME 75, NUMBER 4 FEBRUARY 15, 1949

Mixed Cosmic-Ray Showers at Sea Level*

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(Received October 13, 1948)

A detailed analysis of 15 cloud-chamber photographs of mixed showers is given. This analysis gives the following results: (a) Mixed showers contain, in general, both slow and fast heavy particles in addition to the electron component. Some of the heavy particles can be identified as protons and some as mesons. (b) The electron component of the mixed showers consists sometimes of a single cascade shower and sometimes of several cascade showers. In cases where only a single cascade shower is present its axis is found to be within an angle of 2 or 3 degrees from the direction of the primary particle when this is observable. In cases where several cascade showers appear, one of them often propagates nearly in the direction of the primary particle when this is observable. (c) The simultaneous existence of several cascade showers with their axes diverging at fairly large angles indicates that several high energy electrons or photons are produced in the shower origin. (d) In three cases, an electron group is produced below the shower origin by a non-ionizing particle which seems to originate from the primary nuclear event. These particles may be photons. (e) In one case, two successive nuclear events are observed, which are separated by approximately 60 g/cm^2 of lead. (f) In one case, a star is produced by a penetrating shower particle after traversing approximately 30 g/cm^2 of lead.

I. INTRODUCTION

It has been found recently that some of the cosmic-ray showers produced by penetrating particles consist both of energetic electrons and of particles heavier than electrons.[1,2] Such a shower has been given the name *mixed shower*. Many mixed showers were observed by W. B. Fretter[1] at sea level, and an extensive study of them at high altitude has been made by H. Bridge and W. Hazen.[3] We have also recently taken a series of cloud-chamber pictures for the investigation of shower production by penetrating particles at sea level.[4] In a total of 545 cloud-chamber pictures there were 19 mixed showers produced in the lead plates inside the cloud chamber. The apparatus is described in Section II of the present paper. A detailed analysis of 15 of the mixed showers is given in Section III, and a summary of the results in Section IV. The pictures of the remaining 4 mixed showers are not very clear and do not show points of special interest. Hence they are omitted. For comparison, we include the pictures of one very penetrating shower and of one electron shower.

II. APPARATUS

The cloud chamber was rectangular, 20 inches square and 11 inches deep. For 10 percent of the pictures the chamber contained 9 horizontal lead plates, 12 inches by 10 inches by $\frac{1}{2}$ inch. For the rest of the pictures the lowest lead plate was replaced with an aluminum plate $\frac{1}{16}$-inch thick. The illuminated depth of the chamber was 8 inches. Stereoscopic pictures were taken with an angle of 12° between the two lines of sight.

A tray of 6 Geiger-Mueller counters, each 12 inches long and 1 inch in diameter, was placed just below the cloud chamber, and a second tray of 4 similar tubes was placed 18 inches below the first. The cloud chamber was expanded when any 4 tubes of the upper tray were discharged simultaneously with any two tubes of the lower tray. With this method of triggering, showers could be observed which were initiated by either ionizing or non-ionizing particles. A total of 545 pictures was obtained over a period in which the total sensitive time of the triggering apparatus was 184 hours. It is to be noted that the frequency of showers obtained depends largely on the counter arrangement, which selects

* Assisted by the joint program of the Office of Naval Research and the Atomic Energy Commission.
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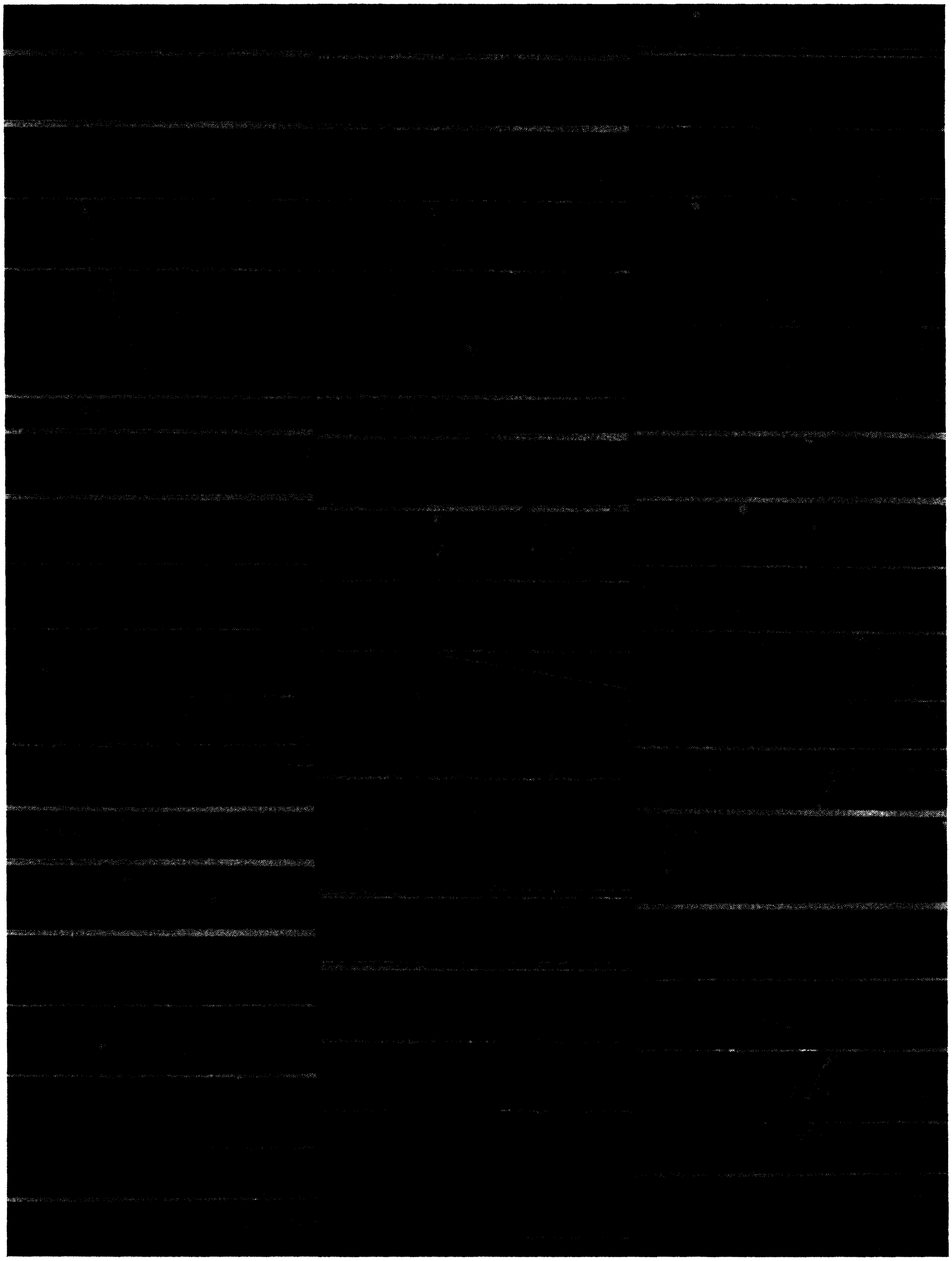
[1] W. B. Fretter, Phys. Rev. **73**, 41 (1948), also other references there.
[2] H. Bridge, W. Hazen, and B. Rossi, Phys. Rev. **73**, 179 (1948).
[3] H. Bridge and W. Hazen, Phys. Rev. **74**, 579 (1948).
[4] C. Y. Chao, Phys. Rev. **74**, 492 (1948).



FIGS. 1–9. Shower Nos. 1–9.

showers of a certain type. Hence it is difficult to compare our results with those of others, with regard to the absolute rate of the events.

III. ANALYSIS OF THE SHOWER PICTURES

For convenience, the showers to be described are divided into the following groups:

(a) The first group contains those showers which have only one prominent electron sub-shower. There are 5 such cases (Shower Nos. 1–5).

(b) The second group contains those showers which have two or more electron sub-showers. There are 9 such cases (Shower Nos. 6–14).

(c) The third group contains one picture giving two showers produced in succession (Shower No. 15).

(d) The fourth group contains one very penetrating shower and one electron shower for comparison.

For identification of individual particles, we make use of the three criterions discussed in a paper by W. M. Powell.[5] They are: (a) the penetrating power of a particle in lead, (b) the rate of increase of ionization near the end of the range, and (c) the angle of scattering in lead. Criterion (a) makes it possible to distinguish between electrons and heavier particles. By means of (b) and (c), we can further distinguish between mesons and particles heavier than mesons. In the following analysis a particle is said to be heavily ionizing if it gives a track which is distinctly more intense than tracks of fast particles in the same location, and it is said to be penetrating if it traverses one or more half-inch lead plates without multiplication.

Group 1

Shower No. 1 (Fig. 1)

Origin.—The shower is produced in the 5th*** lead plate by the ionizing particle *a*, which is seen to traverse 3 lead plates without producing secondaries.

Heavily ionizing particles and penetrating particles.—The shower contains a heavily ionizing particle *b* making an angle of approximately 23° with the direction of the initiating particle in the plane of the picture. No penetrating particle is separately identifiable, possibly because the picture is not very clear.

Electronic component.—The electronic component has a single core making an angle of approximately 2° with the direction of the initiating particle. It contains about 40 electrons at the maximum, hence possesses an energy of about 4 Bev.[6]

Shower No. 2 (Fig. 2)

Origin.—The shower is produced in the 8th lead plate by the ionizing particle *a*, which is seen to traverse 4 plates without producing secondaries. The accompanying track *x* is more diffused and is therefore not simultaneous with the shower.

Heavily ionizing particles and penetrating particles.—The shower contains heavily ionizing particles *b*, *c*, and possibly *d*. Particle *b* goes upwards and has a δ-ray. From the energy and the angle of ejection of the δ-ray, the energy of particle *b*, assumed to be a proton, is estimated to be about 60 Mev. Since the shower starts at the last lead plate, penetrating shower particles can only be recognized if they go upwards. No such penetrating particles are found in this shower.

Electronic component.—The particles of group *A*, about 5 in number, are probably electrons because they have a narrow angular spread which is characteristic of electron groups. The pair *f* may or may not belong to the same group.

Shower No. 3 (Fig. 3)

Origin.—The shower is produced in the 6th lead plate, probably by the ionizing particle *a*, which is seen to traverse 2 plates without producing secondaries.

Heavily ionizing particles and penetrating particles.—The shower contains a heavily ionizing particle *b*, which penetrates one lead plate. Since particle *b* gives heavy ionization both above and below the 7th plate, it is probably a proton.

Electronic component.—The electronic component *A* contains about 10 particles below the 7th plate. It is excited by a non-ionizing particle which is probably produced in the primary interaction in the 6th plate. If this is the case, since

[5] W. M. Powell, Phys. Rev. 69, 385 (1946).

*** This is the actual plate number inside the chamber but not the number counted from the top of the figure since only the important part of the original negative is reproduced here.

[6] S. Belenky, J. of Phys. U.S.S.R. 8, 305 (1944).

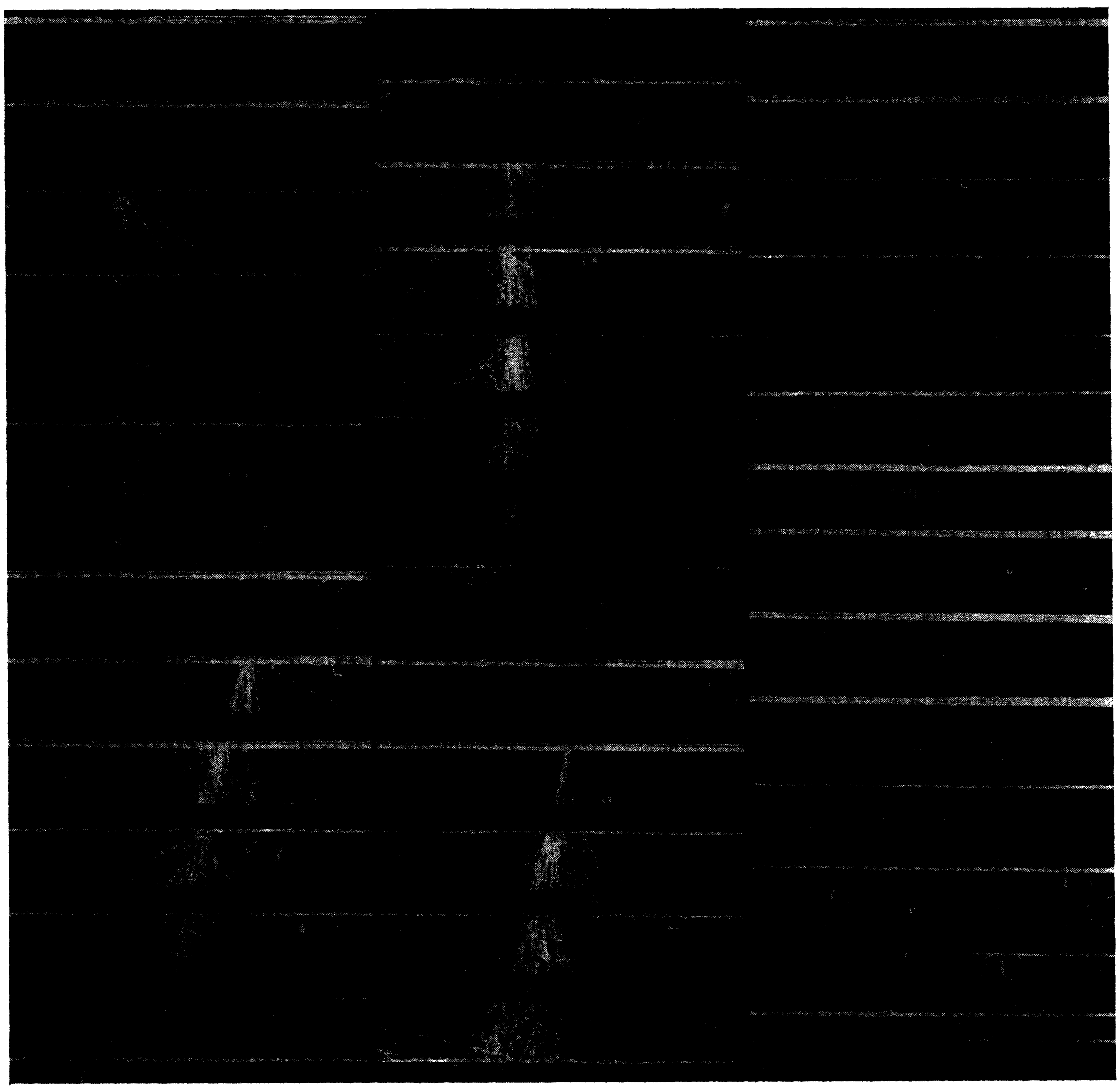
the shower origin is located near the upper surface of the 6th plate, the particle which initiates the electron group traverses more than a half inch of lead before giving rise to the latter. It is rather unfortunate that in the other stereoscopic picture the track of particle a is covered by the bright background of one of the Lucite plate-supporters. The interpretation of this shower is thus made less reliable.

Shower No. 4 (Fig. 4)

Origin.—The shower is produced in the 5th lead plate most probably by the ionizing particle a, which is seen to traverse 4 plates without producing secondaries. The accompanying particle x seems to be simultaneous but is probably unrelated to the shower.

Heavily ionizing particles and penetrating particles.—The shower contains two penetrating particles, b and c. Since particle c gives heavy ionization both above and below the 4th plate, it is probably a proton. The shower contains two additional heavily ionizing particles, d and f, stopping in the 6th plate.

Electronic component.—The electronic component makes an angle of about 2° with the



FIGS. 10–15. Shower Nos. 10–15.

direction of the initiating particle and contains about 30 particles below the 7th plate. The pair g may or may not be an electron pair. Perhaps it gives rise to group h.

Shower No. 5 (Fig. 5)

Origin.—The shower is produced in the 6th lead plate near the rear edge of the illuminated region and is inclined forward. Hence it cannot be established whether the initiating particle is or is not ionizing. The tracks below the 8th plate are slightly displaced towards the right because of convection currents.

Heavily ionizing particles and penetrating particles.—The shower contains one heavily ionizing particle, a, one penetrating particle, b, and possibly another penetrating particle, c. Particle c may be a meson, as is shown by the large deflection in the 7th plate and by its stopping in the 8th plate without giving heavy ionization above that plate.

Electronic component.—The electrons form a single group starting from the shower origin. There are about 15 to 20 particles in the group below the 8th plate.

Shower No. 6 (Fig. 6)

Origin.—The shower is produced in the 5th lead plate, probably by the ionizing particle a, which is seen to traverse 2 plates without producing secondaries. The accompanying tracks, z and y, are apparently simultaneous, but probably unrelated to the shower. The particle b going upwards is found to pass at a little distance in front of the shower origin. It may either have been scattered or produced by a secondary event.

Heavily ionizing particles and penetrating particles.—The shower gives a penetrating particle c. The particle is heavily ionizing below the 6th plate and then passes out of the illuminated region. There may be other penetrating particles which are not easily identifiable individually.

Electronic component.—The shower contains two electron groups (or subshowers). Group A has approximately 20 particles at the maximum, and group B approximately 10 particles. Their energies are, therefore, about 2 Bev and 1 Bev, respectively. The projected angle between them is about 21°. If the two groups were produced by an electron pair which is, in turn, created by a single photon, the average angle of emission of each electron would be of the order of mc^2/U, or about 0.03°. On the other hand, the average angle of scattering of an electron of 1 Bev through one-half inch of lead is about 1.5°. Hence the two groups cannot be produced by a single photon. The projected angle between the axis of group A and the direction of particle a is about 6°. There may be a small group C produced in the 6th plate and stopping in the 7th plate.

*Shower No. 7 (Fig. 7)*****

Origin.—The shower is produced in the 6th lead plate by the ionizing particle a, which is seen to traverse 4 plates without producing secondaries.

Heavily ionizing particles and penetrating particles.—The shower gives two penetrating particles, b and c, at the left side. Particle b is also heavily ionizing. The density of track b decreases as it proceeds because the particle travels from a well illuminated region to the edge of that region. Particle c gives a star in the 8th plate.

Electronic component.—The shower has two electron groups A and B. Each group contains about 20 electrons below the 8th plate. This would mean an initiating energy of about 2 Bev for each group. The projected angle between the two cores is about 15°, which is again much too large if the groups were initiated by a single photon. Group A makes an angle of about 2° with the direction of the initiating particle a.

Shower No. 8 (Fig. 8)

Origin.—The shower is produced in the 6th lead plate, most probably by the ionizing particle a, which is seen to traverse 5 plates without producing secondaries. Behind the track a there is another track which is seen separated from a in the other stereoscopic view. By reprojecting the stereoscopic pictures, this second track is found to pass at a small distance behind the shower origin. The shower contains two particles, b and c, going upwards. Since the track of particle c does not pass through the origin exactly when prolonged backwards, particle c may have been scattered in the lead plate or both particles b and c may have been produced in-

**** This picture was published previously in reference 4 without a detailed analysis.

directly by one of the shower particles emerging from the origin. The two other pairs of tracks above the 6th plate probably also belong to the shower.

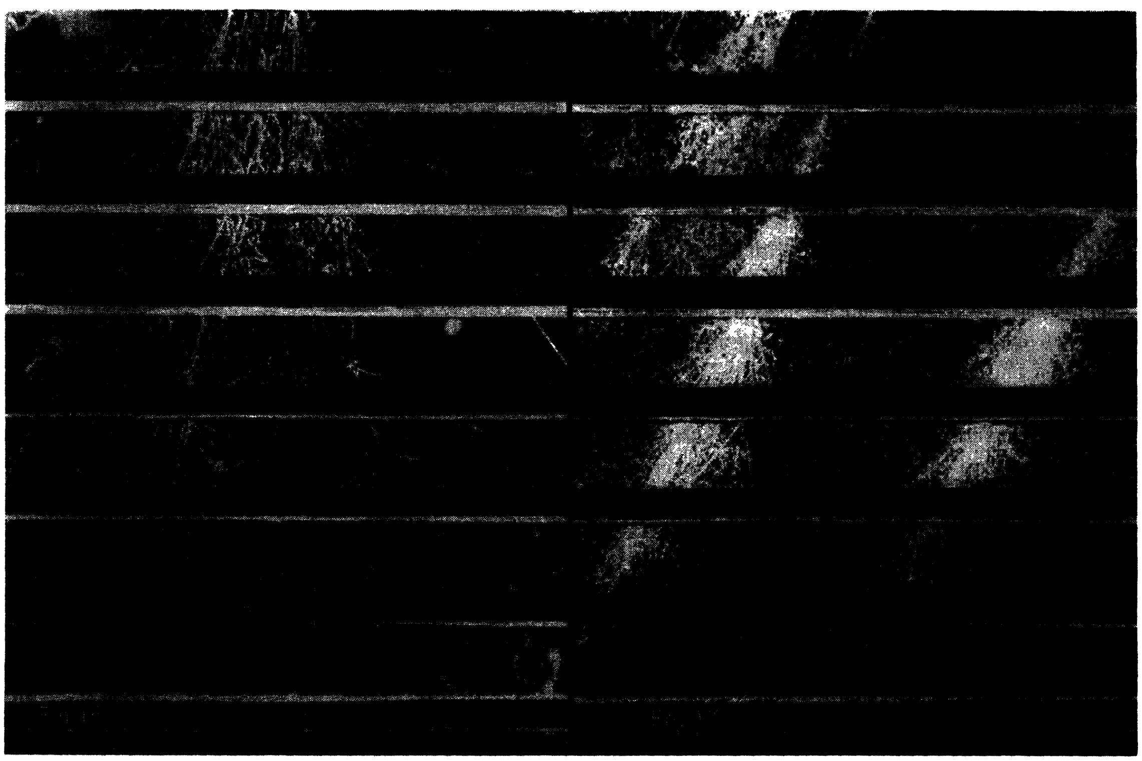
Heavily ionizing particles and penetrating particles.—The shower contains heavily ionizing particles *d*, *f*, *g*, *h*, and possibly also *i*, of which *d* is penetrating. It contains at least 3 other lightly ionizing penetrating particles, *j*, *k*, and *l*. Particle *d* gives rise to a δ-ray. From the energy and the angle of ejection of the δ-ray, the energy of particle *d*, assumed to be a proton, is estimated to be about 30 Mev below the 7th plate, or about 160 Mev in leaving the 6th plate. The density of the track is consistent with this result. Particle *h* passes out of the illuminated region at the rear. The light track which appears coincident with the track of *h* in this view is due to another particle. There is also a δ-ray on the track of *h*, but the angle of ejection of this δ-ray cannot be measured with sufficient accuracy to give a reasonable estimate of the energy of particle *h*.

Electronic component.—The electrons of the shower appear to form at least two groups *A* and *B*. The two groups contain about 15 and 10 particles, respectively, below the 8th plate, and their axes make an angle of about 6° in the plane of the picture. Group *A* is practically in the same direction as the particle *a*. Both groups *A* and *B* seem to start multiplication in the 7th plate. However, group *A* may have started multiplication in the 6th plate and so have the apparent form of the heavy track *i*. Group *B* seems to be produced by a non-ionizing particle emerging from the shower origin. Stereoscopic examination shows that the light track above group *B* in this view is not coincident with the axis of the group.

Shower No. 9 (Fig. 9)†

Origin.—The shower is produced in the 6th lead plate very close to the center of the illuminated region by a non-ionizing particle.

Heavily ionizing particles and penetrating par-



FIGS. 16 and 17. Shower Nos. 16 and 17.

† This picture was published previously in reference 4.

ticles.—The shower contains at least 3 heavily ionizing particles, *a*, *b*, and *c*. Particle *a* seems to traverse the 7th plate and to stop in the 8th plate. Particle *b* gives rise to a δ-ray, from which the energy of this particle, assumed to be a proton, is estimated to be about 60 Mev. Particle *b* may not belong to the shower, or both *b* and *c* may originate from a secondary process of one of the shower particles emerging from the primary origin. The general form of the shower shows that it must contain quite a number of penetrating particles. The penetrating particle *d*, which can be traced back to the shower origin stereoscopically, is seen to be a meson from the angles of deflection in the lead plates.

Electronic component.—The electrons can be attributed to two main groups, *A* and *B*, each containing about 15 particles below the 8th plate. The axes of the two groups make an angle of approximately 15° in the plane of the picture. There are two more small groups, *C* and *D*. Group *C*, containing about 5 particles, appears to be produced by a non-ionizing particle, which is probably emitted in the primary event. If this is the case, the initiating particle of group *C* must travel through more than a half-inch of lead before giving rise to the electron group.

Group 2

Shower No. 10 (Fig. 10)

Origin.—The shower is produced in the 5th lead plate by the ionizing particle *a*, which is seen to traverse 3 plates above the shower origin with only the production of a knock-on electron in the 4th plate.

Heavily ionizing particles and penetrating particles.—The shower contains two heavily ionizing particles, *b* and *c*. There is a light track below the end of track *c* in the figure. These two tracks are found to be unrelated to each other by stereoscopic examination. The general shape of the shower indicates that it contains a number of penetrating particles. The penetrating particle *d* traverses 3 lead plates.

Electronic component.—There seem to be at least two electron groups, *A* and *B*, each containing about 10 particles below the 7th plate. The axes of the two groups make an angle of about 10° in the plane of the picture. Group *A* is nearly in the same direction as the initiating particle and propagates through the 8th plate. (The tracks below the 8th plate are displaced toward the right by a convection current.)

Shower No. 11 (Fig. 11)

Origin.—The shower is produced in the 3rd plate, possibly by the ionizing particle *a*. The track xx' passes very close to the origin but is probably unrelated to the shower. The shower contains at least 3 particles, *b*, *c*, and *d*, going upwards.

Heavily ionizing particles and penetrating particles.—The shower contains at least two heavily ionizing particles, *b* and *f*, emerging from the origin. There is another heavily ionizing particle†† below the 8th plate, which may or may not belong to the shower. The shower possibly contains a number of penetrating particles, as seen from the general shape.

Electronic component.—The electrons seem to form two groups, the main group *A* containing about 50 particles at the maximum and a less distinct small group *B* containing about 15 particles at the maximum. The axes of *A* and *B* make projected angles of approximately 4° and 10°, respectively, with the direction of particle *a*.

Shower No. 12 (Fig. 12)

Origin.—The shower is produced in the 3rd lead plate probably by the ionizing particle *a*. This seems most likely, since it is observed that there is often a prominent electron group which propagates nearly in the direction of the initiating particle when the latter is observable. There are 3 particles, *b*, *c*, and *d*, going upwards.

Heavily ionizing particles and penetrating particles.—The shower contains a number of penetrating particles. Particles *d*, *f*, and *g* traverse at least one lead plate, *h* at least two plates, and *i* stops in the 8th plate. Particle *i* gives heavy ionization both above and below the 7th plate; it is, therefore, probably a proton. In addition to *i*, there are two heavily ionizing particles, *j* and *k*. There is another interesting particle, *l*, which gives rise to a δ-ray. Most likely, particle *l* is a meson or proton since it is not appreciably deflected by the collision.

†† The track of this particle is not in the figure.

Electronic component.—The electrons seem to belong to two groups, a larger group A propagating nearly in the direction of particle a and a smaller group B. The two groups have their axes making an angle of about 5° and largely overlap each other. They jointly give about 50 particles at the maximum below the 6th plate.

Shower No. 13 (Fig. 13)

Origin.—The shower is produced in the 4th lead plate by the ionizing particle a, which is seen to traverse 3 plates without producing secondaries. The tracks x and y are inclined at much larger angles toward the rear of the cloud chamber than the track a, and are therefore unrelated to the shower. Track x looks also older than the shower tracks.

Heavily ionizing particles and penetrating particles.—The shower contains at least two heavily ionizing particles, b and c, emerging from the origin. The heavily ionizing particles, d and f, may or may not belong to the shower. The shower contains a number of identifiable penetrating particles, g, h, i, and j. Particle h is probably a meson, as indicated by the large deflection in the 5th plate.

Electronic component.—The core of the shower appears to propagate in the direction of the initiating particle a and to fan out continuously from the origin. This may be due to the presence of penetrating particles or of several electron groups making small angles between themselves, or due to both causes. The maximum number of the shower particles occurs below the 6th plate and is about 50. The small group A contains about 10 particles.

Shower No. 14. (Fig. 14)

Origin.—The shower is produced in the 6th lead plate at the rear edge of the illuminated region and is inclined forwards. Hence the character of the initiating particle cannot be determined.

Heavily ionizing particles and penetrating particles.—The shower contains at least 3 penetrating particles, a, b, and d. They are heavily ionizing both above and below the 7th plate, though their tracks near the origin are rather faint because of the weak illumination in that region. Hence particles a, b, and d are probably protons. From the δ-ray on its track, the energy of particle d, assumed to be a proton, is estimated to be about 100 Mev below the 7th plate, or about 200 Mev as it leaves the 6th plate. There probably are other penetrating particles, but their identification is not very conclusive. Particle c is heavily ionizing, and cannot be traced beyond the 7th plate.

Electric component.—The shower contains two groups of electrons A and B, each containing about 5–10 particles. Because of a convection current at the left corner below the 8th plate, group B is somewhat displaced toward the right, and consequently it is impossible to determine its initiating particle. It is, however, certain that group B is not a continuation of group A, because the horizontal distance between the two groups as shown in the picture is greater than the possible displacement due to such a disturbance and, furthermore, group B appears to be nearer to the front than group A. Hence, group B is most likely produced in the 8th plate by a shower particle from the primary origin.

Group 3

Shower No. 15 (Fig. 15)

Origin.—There are two showers in this picture. The first shower is produced in the 3rd lead plate by the ionizing particle a. The second shower appears to be produced in the 7th plate by an ionizing particle which comes out of the center of the first shower exactly in the direction of particle a. It may be the same particle, or a secondary particle which takes most of the momentum of the primary particle. The accompanying track x is sharper than the shower tracks and is therefore not simultaneous with the two showers.

Heavily ionizing particles and penetrating particles.—The first shower contains only about 10 tracks. One track corresponds to a very penetrating particle b, making a small angle with particle a and traversing at least 4 lead plates. A second track corresponds to a penetrating particle c. This track becomes heavier each time the particle traverses a lead plate between the 3rd and the 6th. The increase of ionization is consistent with the assumption that the particle is a proton. From the δ-ray on the track of particle c, the energy of this particle, if it is a proton, is estimated to be about 200 Mev below the 4th plate or about 250 Mev in leaving the 3rd plate. This is consistent with the range of the particle in lead.

The second shower has several particles going upwards. It contains about 9 heavily ionizing particles, of which particles d, f, i, j, and k are very prominent. Particles i, k, l, and m penetrate the 8th lead plate. It is possible that particle k gives a group of 3 particles below the 8th plate. Poor illumination makes it difficult to decide whether or not these particles are heavily ionizing.

Electronic component.—In the first shower there is no electron group which can be identified with certainty. In the second shower, group A may be composed of electrons. It contains 5 or more particles below the 8th plate, and its axis makes an angle of approximately 18° with the initiating particle of the second shower in the plane of the picture. There is another small group B, which may also consist of electrons belonging to the second shower.

Group 4

Shower No. 16 (Fig. 16)

This is a very penetrating shower, produced in the upper wall of the cloud chamber or somewhere above the chamber. The tracks below the 8th plate are displaced towards right by about one-third inch in a full size view by a convection current. The shower contains many penetrating particles. Some of them are individually identifiable, such as a, b, c, d, f, g, h, i, j, and k on the figure. Particle k is probably a proton as it gives heavy ionization both above and below the 4th lead plate. Particle c seems to be a meson because it is deflected through a large angle at the 2nd lead plate and stops in the 3rd plate without having very heavy ionization above that plate.

The electronic components in this shower are not very prominent.

Shower No. 17 (Fig. 17)

This is a group of showers produced in the lead plates by a number of high energy electrons and photons belonging to an air shower. These electrons and photons are inclined at approximately 15° toward the back of the chamber and 35° toward the left. The two largest showers contain several hundred electrons each, at the maximum, and thus indicate energies of the order of several tens of Bev. A number of stars are seen in the picture.

IV. SUMMARY OF RESULTS

From the foregoing analysis we can summarize the following conclusions: (a) Of the 15 mixed showers produced in the lead plates, all contain heavily ionizing particles. Fifteen of these particles are seen to penetrate one or more lead plates after they become heavily ionizing. They are identified as protons or particles still heavier than protons. In addition to these, there are 18 individually recognizable penetrating particles which are lightly ionizing. They may be fast mesons or fast particles heavier than mesons. One of them is identified as a meson by its large scattering in two lead plates (in Shower No. 9). There are two other penetrating particles which are scattered only once in lead through a large angle. They are probably also mesons.

(b) The electron component of the mixed showers consists sometimes of a single cascade shower and sometimes of several cascade showers. In cases where only a single cascade shower is present, its axis is found to be within an angle of 2 or 3 degrees from the direction of the primary particle when this is observable. In cases where several cascade showers appear, one of them often propagates nearly in the direction of the primary particle when this is observable.

(c) The simultaneous existence of several cascade showers with their axes diverging at fairly large angles indicates that several high energy electrons or photons are produced in the shower origin.

(d) In three cases, an electron group is produced below the shower origin by a non-ionizing particle which seems to originate from the primary nuclear event. (Shower Nos. 3, 8, and 9.) The energy required to produce these electron groups is of the order of 1 Bev. The particles which initiate these groups would not seem to be neutrons because neutrons would not be likely to produce electron showers unaccompanied by heavy particles. If one assumes that the initiating particles are photons from the shower origin, one must consider two of the three cases, in which the particles traverse more than a half-inch of lead before giving rise to the electron groups. (Shower Nos. 3 and 9.) Since the probability that photons of 1 Bev will traverse so much lead without undergoing materialization is about 0.2, the photon hypothesis can account for the observations.

(e) In one case a penetrating particle produces a nuclear event in one lead plate, and one of the shower particles, which may be the primary particle itself, produces a mixed shower after traversing 60 g/cm^2 of lead.

(f) In one case a star is produced by a penetrating shower particle after traversing approximately 30 g/cm^2 of lead.

The foregoing results about the electron groups of the mixed showers comply with the assumption that these groups originate from photons or electrons produced either directly in the nuclear interactions or indirectly through the decay of short-lived mesons produced in these interactions.

ACKNOWLEDGMENTS

The author is grateful to Professor Bruno Rossi for his encouragement during the course of this experiment, and to Mr. H. Bridge and Mr. R. J. Davisson for their suggestions and help. He is also indebted to Professor G. E. Valley and Mr. A. L. Jerrems who designed and built the cloud chamber.

PHYSICAL REVIEW VOLUME 75, NUMBER 4 FEBRUARY 15, 1949

East-West Asymmetry and Latitude Effect of Cosmic Rays at Altitudes up to 33,000 Feet*

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(Received October 28, 1948)

By means of triple coincidence telescopes mounted in a B-29 airplane, the east-west asymmetry of cosmic rays has been measured at several geomagnetic latitudes from 0 degrees to 41 degrees north. The asymmetry was determined separately for the hard, soft, and shower producing components of the radiation. At a zenith angle of 45 degrees, the intensity of each of these components from the western direction exceeded that from the eastern direction by an amount which increased rapidly as the geomagnetic latitude was decreased. Comparison of the amount of asymmetry with the observed latitude effects permits the conclusion that all components arise from primary rays which in the range of energies explored by the experiment are all or nearly all positively charged.

During the course of the experiments, vertical intensities of the hard and soft components were also measured. Data on the variation of the vertical intensities with altitude and with geomagnetic latitude are presented.

I. INTRODUCTION

THE theory of the geomagnetic effects on charged particles has been worked out by Stoermer[1] and Lemaitre and Vallarta[2] and others so that quantitative conclusions about the primary cosmic rays can be drawn from observations of the cosmic-ray particles found in the earth's atmosphere. Measurements of the latitude effect give information about the momentum spectrum of the primary particles, and when the momentum spectrum is known, observations of the east-west asymmetry can be used to determine the sign of the charge of the primary particles.

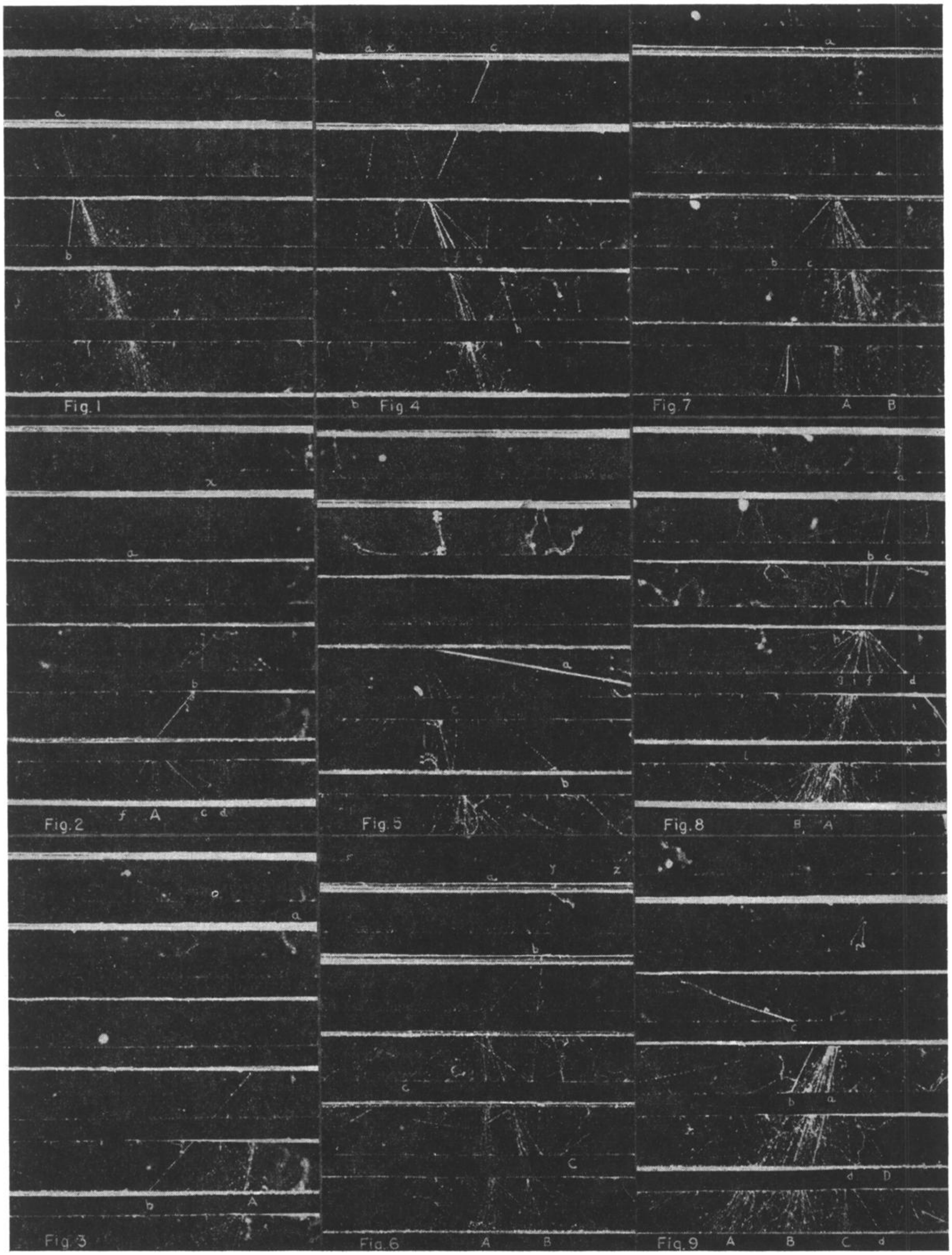
Many ground level east-west asymmetry ex-

* This work was supported in part by the Atomic Energy Commission and the Office of Naval Research.

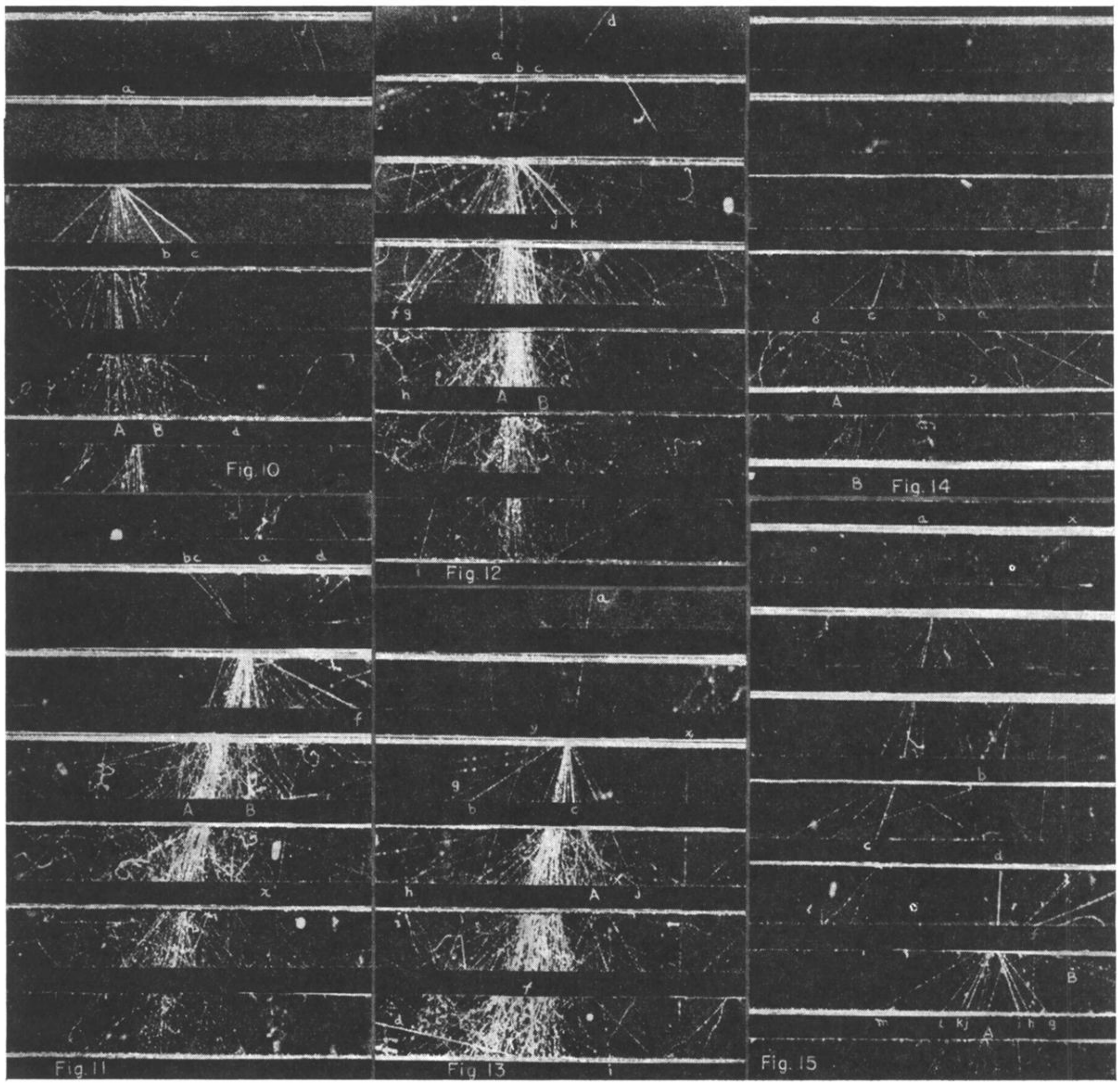
** Now at Stanford University.

[1] C. Stoermer, Vid. Selsk. Skr. Christiana (1904, 1913).

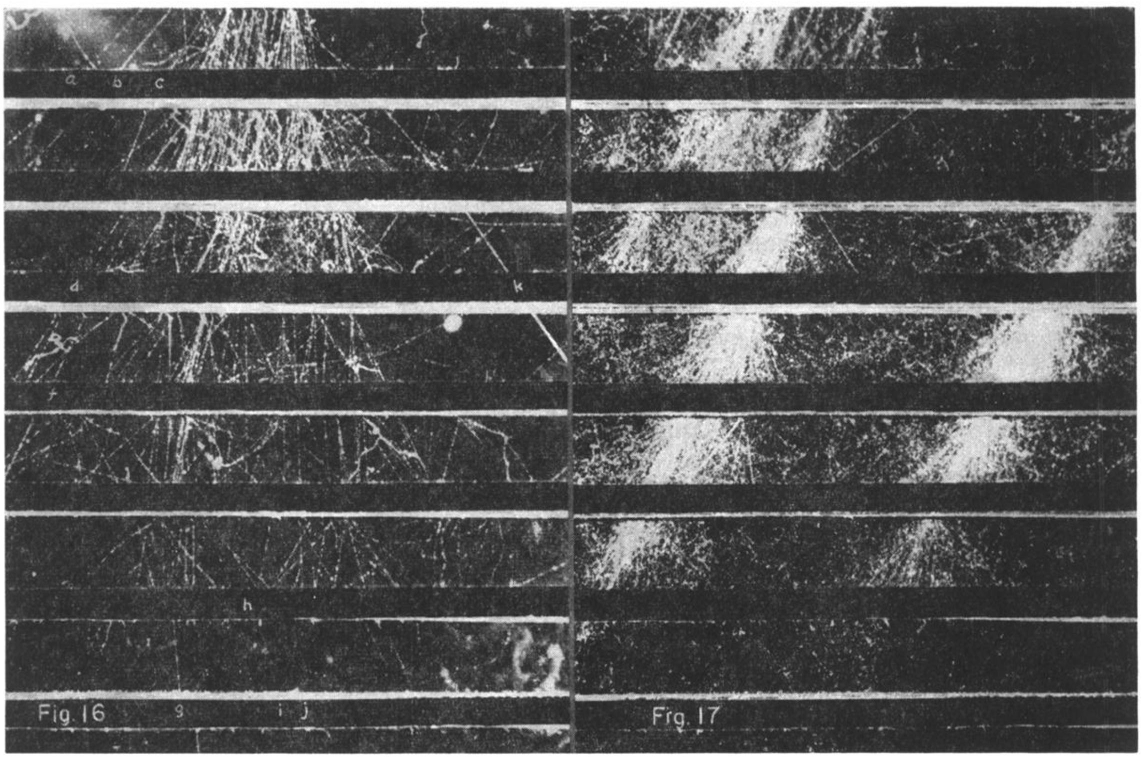
[2] G. Lemaitre and M. S. Vallarta, Phys. Rev. 50, 493 (1936).



FIGS. 1–9. Shower Nos. 1–9.



Figs. 10–15. Shower Nos. 10–15.



FIGS. 16 and 17. Shower Nos. 16 and 17.