Study of Cosmic-Ray Air Showers With the Method of Coincident Bursts in Two Unshielded Ionization Chambers

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Cosmic-ray bursts of ionization occurring in each of two unshielded, thin-walled ionization chambers were recorded simultaneously on a single piece of photographic film. This recording made it possible to study events in each chamber separately, and also to determine when a burst, occurring in one chamber, was coincident in time with a burst in the other. The graphic relation between the size of bursts and their frequency is given for a single chamber and for the coincident bursts. The relation, between burst coincidence frequency and separation of the chamber for several burst sizes, is given in a separate graph. A study of these sets of curves reveals the presence of many high density cosmic-ray air showers of heretofore unsuspectedly small lateral spread. These showers cannot originate at the top of the atmosphere but must be a secondary phenomenon.

INTRODUCTION

COSMIC-RAY Geiger-Müller counter experiments of the type performed by Auger[1] have led to the application of the cascade theory to the analysis of extensive atmospheric cosmic-ray showers. More recent Geiger-Müller counter tube measurements[2] of air showers have shown a large increase in counting rate with altitude. Computations[2] of this increase have been made by using the cascade theory of showers in combination with various assumed energy spectra for the shower producing radiation. The calculated counting rates as a function of altitude do not agree, however, with the observed curve over the whole range of observation.

Lapp[3] has shown that large bursts observed in an unshielded ionization chamber are caused by the passage through the chamber of the high density part of air showers. He used Geiger-Müller counter coincidences in conjunction with a Carnegie Model C meter. This experiment shows that the observed very large increase in burst rate with altitude[4, 5] must be due to an increase in the frequency of air showers.

All computations, used for the comparison of shower experiments with the cascade theory, necessitate introducing either a mean width of the showers or a lateral density distribution function for the shower particles. This does not permit these experiments to provide a sensitive test of the theory. For the present investigation, an experimental method suggested by Euler[6] was chosen. It was expected that this method would provide a better test of the cascade theory. Euler pointed out that the observation of coincident bursts of ionization in two unshielded ionization chambers could lead to the determination of the lateral distribution of electrons in air showers. In the same paper, Euler calculated the burst coincidence frequency as a function of chamber separation. This calculation, which was carried out only for sea level, was based on an assumed energy spectrum of primary electrons and made use of several simplifying assumptions. The curves computed by Euler are for such high particle densities and, hence, for such low burst rates that they can be observed only in a prohibitive length of time.

Professor Marcel Schein has suggested that the measurement of coincident burst frequency as a function of chamber separation should be made at several altitudes. This would provide a method of determining both the energy spectrum of the shower-producing radiation and the lateral density distribution of the shower particles, provided that the showers originate close to the top of the atmosphere and that the cascade theory is

[1] P. Auger, R. Maze, and T. Grivet-Meyer, Comptes Rendus **206**, 1721 (1938).
[2] N. Hilberry, Phys. Rev. **60**, 1 (1941).
[3] R. E. Lapp, Phys. Rev. **64**, 129 (1943).
[4] C. G. Montgomery and D. D. Montgomery, Phys. Rev. **47**, 429 (1935).
[5] C. G. Montgomery and D. D. Montgomery, Rev. Mod. Phys. **11**, 255 (1939).
[6] H. Euler, Zeits. f. Physik **116**, 73 (1940).

correct in the domain of very high energies. This would eliminate the necessity of using an assumed primary energy spectrum in order to determine the lateral density distribution.

APPARATUS

The ionization currents produced in each of two thin-walled ionization chambers were amplified by d.c. amplifiers employing inverse feedback. Each amplifier output was connected to a string galvanometer. The deflections of both galvanometers were recorded simultaneously and continuously on the same photographic film. Coincidences between bursts of ionization in the two chambers were detected by measurement of the photographic traces with a microscope fitted with a filar-eyepiece.

The ionization chambers were steel spheres 35 cm in diameter with a wall-thickness of 0.03 cm. Each chamber had a cylindrical side-arm 7.6 cm in diameter and 20 cm long. This side-arm contained an FP-54 vacuum tube and tube shield. The collecting electrode of the ionization chamber consisted of a 7.5 cm diameter copper sphere with a 0.04 cm wall thickness and was mounted directly on the grid cap of the FP-54 tube, thus reducing the input capacity of the whole amplifier to a minimum. Each chamber with its side-arm was a single vacuum-tight volume and was filled with very pure argon to a total pressure of 100 cm Hg. A schematic cross section through the ionization chamber is given in Fig. 1.

The amplifier circuits were of a type similar to circuits described by Harnwell and Ridenour[7] and others,[8, 9] but with the essential modification of the feedback connection being made to the first grid of the FP-54 vacuum tube rather than to the well-insulated second grid. This modification enabled the circuit to be sufficiently fast in its response to follow the rapid changes in the ionization current produced by a burst, and, in addition, to have inverse feedback characteristics. At the same time, the use of a large input grid resistor (10^{12} ohms) was possible. Tests for frequency response in a circuit with this feedback feature showed that the circuit had the same over-all amplification for square wave input of 3000 cycles per second that it had for direct currents. The driving signal was put across the large input grid resistor (10^{12} ohms).

The galvanometer strings were platinum wires of 0.0025 mm diameter. Each wire was 20 cm long. These strings were mounted so that each passed between carefully machined, wedge-shaped pole pieces of Alnico permanent magnets. A microscope objective focused an image of each string on a moving photographic film. A fine slit was placed directly in front of the film. This photographic registration permitted coincident bursts to be detected within a time of 0.2 second for the rate of travel of film used (75 mm/hour). This time was sufficiently short, since it was smaller than the collection time of the ions in

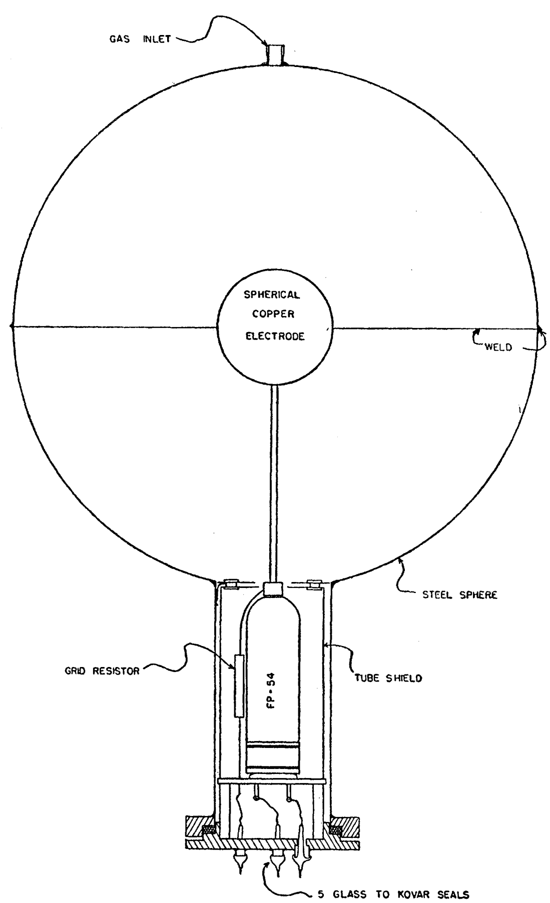

FIG. 1. Schematic cross section through an ionization chamber and its cylindrical side-arm. The line across the center of the chamber represents a weld between two hemispherical steel spinnings, and is not a partition through the chamber.

[7] G. P. Harnwell and L. Ridenour, Rev. Sci. Inst. 11, 346 (1940).
[8] Vance, Rev. Sci. Inst. 7, 489 (1936).
[9] Roberts, Rev. Sci. Inst. 10, 181 (1939).

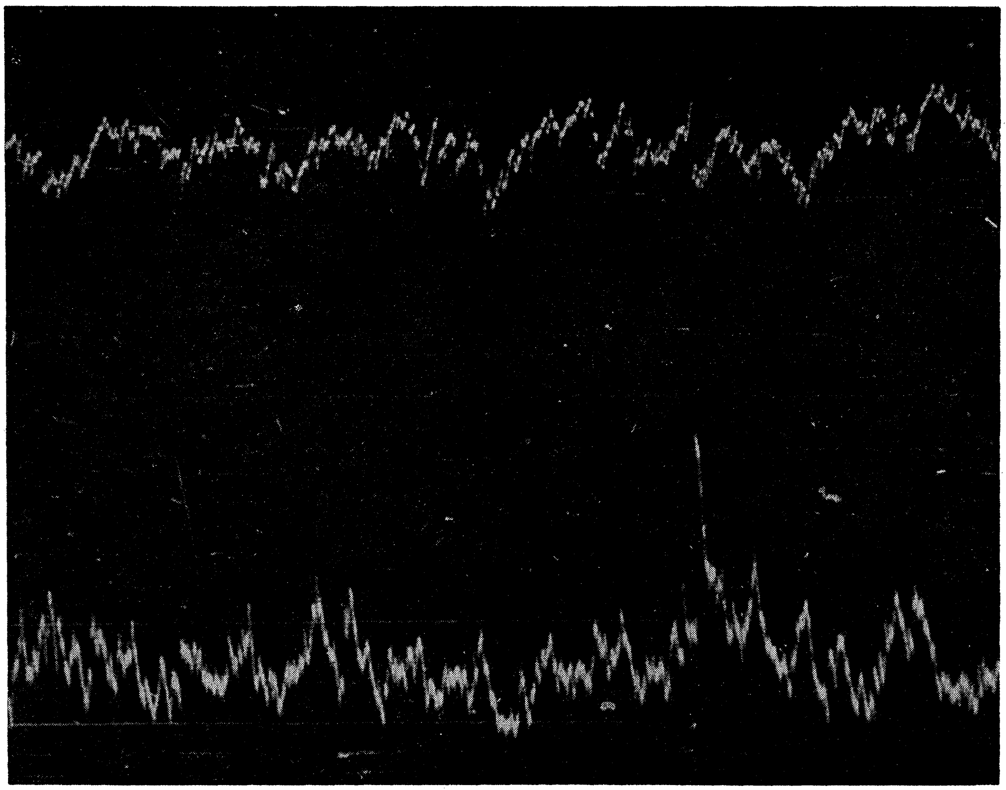

FIG. 2. A reproduction of a portion of the photographic trace taken at a chamber separation of four meters.

the chamber. The wedge-shaped pole pieces on the galvanometer magnets produced a non-homogeneous magnetic field in the regions of the strings which increased the compression of the scale for the larger deflections. Currents as small as 0.006 of the maximum galvanometer current measurable on the film could be determined with an accuracy of about 3 percent, and, therefore, burst sizes producing amplifier output currents as small as this could be measured accurately. With the string tension used in this experiment, the galvanometers would follow 60-cycle alternating current with no noticeable change in sensitivity. However, there was approximately 20 percent decrease in current sensitivity at 200 cycles per second. These data show that the galvanometers were capable of following all changes in ionization current expected for the collecting time of the ions used in this experiment (0.4 sec.).

The apparatus was mounted in two portable houses which were equipped with sensitive thermostats (maximum variation 0.3°C). These houses were designed for Wilson cloud-chamber measurements of air showers. The constant temperature reduced the drift of the zero points of the amplifiers and galvanometers and insured constancy of the current calibration of each galvanometer.

The pressure of argon in the chambers was chosen so that the smallest burst analyzed (containing 80 cosmic-ray particles) would give a voltage signal (about 0.001 volt) which was large, compared to the noise level of the amplifier. The gain of the amplifier was then adjusted so that bursts of 80 particles would give galvanometer deflections large enough to be measured accurately. An over-all calibration of the apparatus was made frequently, during the time of the measurements, by recording the galvanometer deflections produced by known voltage signals put between the collecting electrode and the outer sphere of the ionization chambers. For a total input capacity of 15 mmf a deflection of

1 mm, as seen in the eyepiece of the microscope used for analyzing the photographic film, corresponded to a charge of $(7.83\pm0.06)\times10^{-14}$ coulomb for one chamber and $(7.95\pm0.06)\times10^{-14}$ coulomb for the other. A section of the photographic registration on a film taken at a 4-meter separation of the chambers is shown in Fig. 2.

DATA

The present paper deals only with data taken at Echo Lake, Colorado, altitude 10,650 ft. An open location of the apparatus was chosen so that the data would not be influenced by any large rock mass at the side or above the apparatus. Approximately 60,000 bursts were recorded in the two ionization chambers. These bursts were observed with the chambers placed in the two portable houses referred to above. Each house had a roof made from a piece of Douglas fir plywood, one-quarter inch thick. These roofs were constructed of material of low atomic number and with as little mass as possible, so that there would be a negligible multiplication of the shower particles passing through them.

The results of the observations are represented in Fig. 3 and Fig. 4. In Fig. 3, the number of burst coincidences per hour is plotted against the separation of the ionization chambers. These separations were measured from the center of one chamber to the center of the other chamber. The upper curve in Fig. 3, labeled ">80 particles per chamber," gives, as a function of chamber separation, the total number of burst coincidences per hour caused by more than 80 cosmic-ray particles traversing *each* chamber simultaneously. The three other curves in Fig. 3 give the number of burst coincidences per hour as a function of chamber separation for coincidences caused by more than 160, 240, and 320 cosmic-ray particles, respectively, traversing each chamber simultaneously.

In Fig. 4, the total number of burst coincidences per hour, caused by the simultaneous passage of more than a given number of particles through each chamber, is plotted against that given number of particles. The top curve gives this relation for zero separation of the chambers. The zero separation burst-coincidence frequency is numerically equal to the burst frequency in a single chamber. The four other curves give the total number of coincident bursts per hour, caused by the simultaneous passage of more than a given number of particles through each chamber, as a function of that given number of particles for chamber separations of 39 cm, one meter, four meters, and ten meters, respectively.

It will be noticed that the size of burst is given in terms of the number of particles traversing the chamber simultaneously, rather than in terms of electrical charge. This method of presentation was used in order to make the results more readily comparable with theoretical calculations. The usual computations from shower theory give number of particles per unit area, rather than ionization per unit volume. The relation between total charge developed in the chamber and the number of particles producing that charge was determined from experimental results and from calculations as follows.

Corson and Brode,[12] using delayed expansions in a cloud chamber filled with nitrogen, have measured the specific ionization of electrons. The chamber was placed in a magnetic field. These measurements provide an experimentally determined, specific ionization of electrons over a large range in particle energy. Swann[13] has determined the ratio of specific ionization in argon to that in nitrogen as 1.46. A combination of this value with the results of Corson and Brode gives the values of the specific ionization in number of ion pairs per cm path length shown in Table I.

For the separations of the chambers used at Echo Lake, Colorado, the contribution to the bursts of ionization in the ionization chambers by electrons of less than 10^6 ev, or of more than 10^{10} ev, is not large. Table I indicates that an average value of 100 ion pairs per cm path length may be used. This value is probably too low for the larger burst coincidences and is probably too high for the small bursts, especially at the larger chamber separations.

The average length ($\bar{L}$) of the path of a particle passing through the chamber is given by

$$\bar{L}=4/3\pi R^3\div\pi R^2=4/3R, \qquad (1)$$

where R = radius of chamber.

[12] Corson and Brode, Phys. Rev. **53**, 773 (1938).
[13] W. F. G. Swann, Phys. Rev. **44**, 961 (1933).

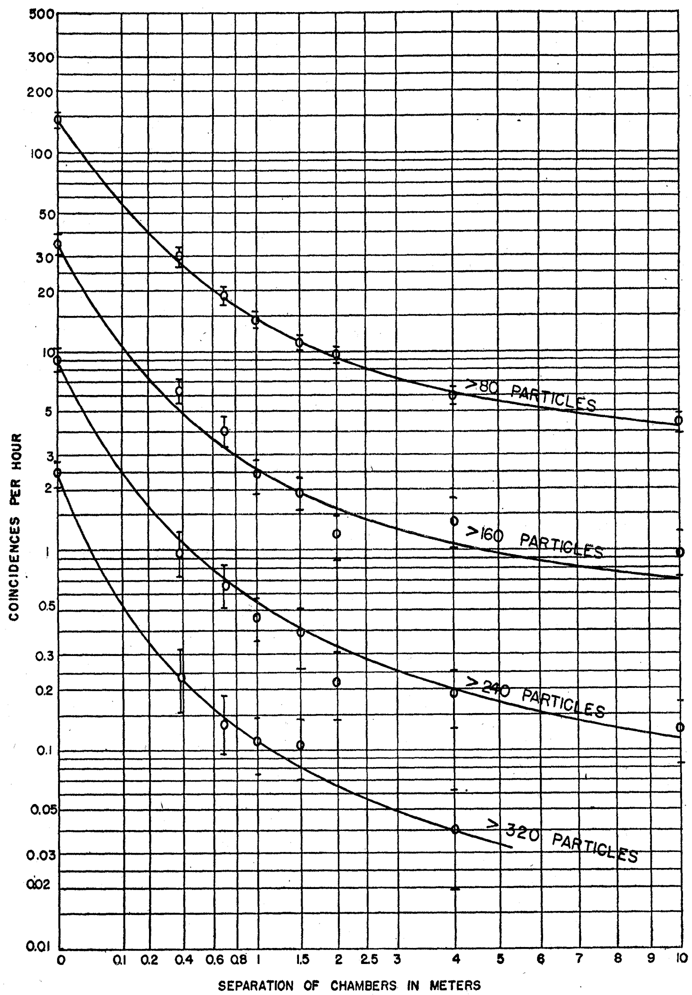

FIG. 3. The four curves of this graph give the number of burst-coincidences per hour, as a function of separation of chambers in meters, for coincidences caused by more than 80, 160, 240, and 320 cosmic-ray particles, respectively, traversing each chamber simultaneously.

For an argon pressure of 100 cm Hg and a chamber diameter of 35 cm, the charge generated by an 80 particle burst is then

$$80 \text{ part.} \times \left(\frac{4}{3} \times \frac{35 \text{ cm}}{2 \text{ part.}}\right) \times 100 \frac{\text{ion}}{\text{cm}} \times \frac{100}{76} \times 1.59 \times 10^{-19} \frac{\text{coul}}{\text{ion}} = 3.90 \times 10^{-14} \text{ coul.} \quad (2)$$

This value was used to determine the number of particles per burst in all the results given in Fig. 3 and Fig. 4.

It is established[2] that the large increase in shower counting rate with increasing altitude is caused primarily by the increase in the frequency of showers of lower energy. This indicates that the barometric coefficient for the smaller showers is quite different from that for the larger showers. This causes difficulty in correcting the burst-coincidence rates for changes in barometer, since a given size burst may have been caused by a smaller shower striking near the apparatus, or by a larger shower striking farther away. In order to make a suitable correction, it would be necessary to know both the sizes of all showers contributing to a given point on the graphs of

TABLE I. Specific ionization in one atmosphere of argon.

Energy of electron in electron volts	Number of ion pairs per cm path length
10^6	70
10^7	82
10^8	102
10^9	124
10^{10}	146

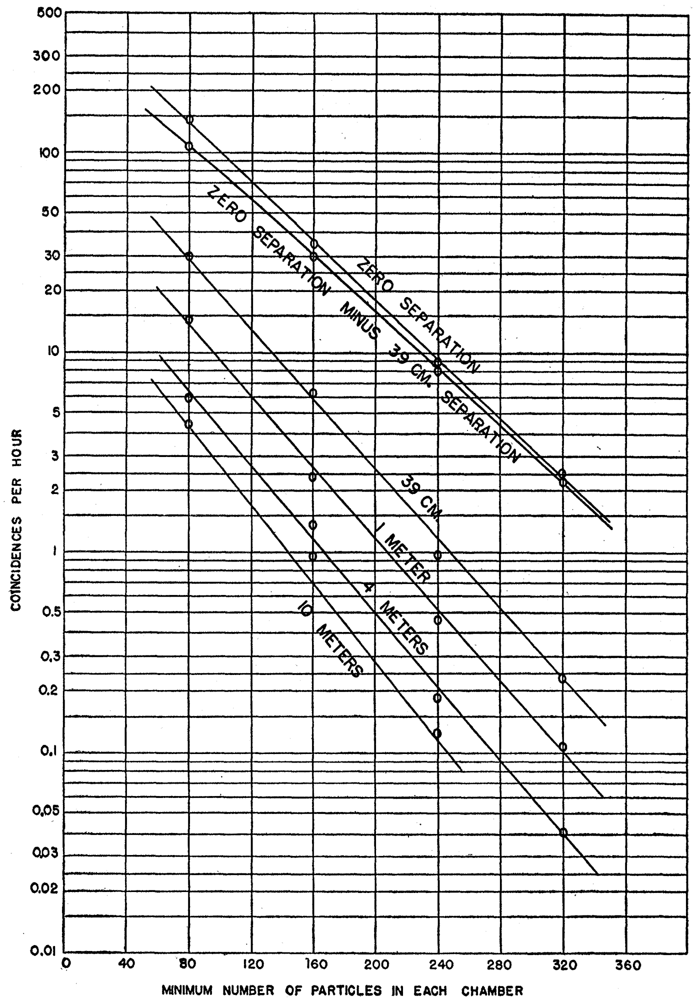

FIG. 4. This graph gives the total number of coincident bursts per hour caused by the simultaneous passage of more than a given number of particles through each chamber as a function of that given number of particles, for various separations of the two chambers.

Fig. 3 and Fig. 4, and the barometric coefficient for the showers of different size. Because of this difficulty, no attempt has been made to correct these data for barometric changes. The same difficulties are encountered in attempting a correction for changes in temperature. Therefore, the error limits associated with the experimental points in Fig. 3 are drawn to represent the sum of the probable error plus the observed mean fluctuation of the hourly rates due to atmospheric changes. The error limits on the ">80 particles per chamber" curve, Fig. 3 are almost entirely caused by atmospheric changes.

The time required for an ion to travel from the outer sphere to the inner collecting sphere of the ionization chamber was computed for one atmosphere of argon and an ion mobility of 2.4 cm/sec. per volt/cm. The time calculated was 0.65 sec. for the sweep voltage of 240 volts. The time necessary for the collection of all the ions generated in a burst was measured by determining the time required for the galvanometer string to move from its initial position to the final position produced by the burst. Careful measurements on many bursts yielded a result of 0.4 ± 0.1 sec. The resolving time of the apparatus was, therefore, taken as 0.4 second. This is justified since the electrical circuits and the galvanometers were capable of recording considerably faster changes in the ionization current, and, in addition, the trace on the photographic film could be measured within a time interval smaller than 0.4 sec. This collecting time was used in conjunction with the observed burst rates in a single chamber to compute the chance coincidence rates of bursts. These chance coincidence rates limited the maximum separation of the ionization chambers to about 10 meters for bursts of 80 particles at 10,650 ft. altitude. The data given in Fig. 3 and Fig. 4 are corrected for the chance coincidence rates computed in the usual manner. The results of these experiments indicate that a resolving time of about a few thousandths of a second would be required for this type of apparatus to work successfully at elevations considerably higher than 10,650 ft. and at separations of chambers as large as 50 meters.

Tests for the internal consistency of the data were made. The first test was a separate study of the size-frequency distribution curves for all the bursts in each chamber. The absolute values of the size-frequency distribution curves obtained from one chamber for a particular hour closely approximated the curves from the other chamber for the same hour. Actually, the absolute values in the size-frequency distribution curves for one chamber changed from hour to hour; but since the variations in both chambers always occurred together, they could be explained only by changes in atmospheric conditions such as temperature and barometric pressure. This is demonstrated in Table II, which gives the number of bursts greater than 80 particles occurring separately in each chamber for several one-hour periods selected at random from the data taken over a period of several days.

Table II indicates also the magnitude of the fluctuations in the burst rate in a single chamber. Very few hours had a single rate as high as is indicated in Table II for the hour K. The hourly variations in the burst-coincidence rates were found to be smaller than the corresponding variations in the single chamber rates. These variations in the coincidence rates are included in the error limits in Fig. 3, as previously explained.

A measurement of the total ionization current produced in one chamber by all ionizing rays was made by measuring the voltage drop across the large grid resistor of the FP-54 tube. Since the exact value of this resistor was not known, the value of the total ionization current determined this way cannot be considered as very exact. The manufacturer measured the value of this resistor as 1.0×10^{12} ohms. With this value, the total ionization current was found to be 2×10^{-13} ampere.

TABLE II. Bursts of greater than 80 particles in one-hour periods selected at random.

Hour	Number of bursts in one chamber Chamber I	Chamber II
A	131	127
B	130	131
C	113	117
D	127	116
E	140	135
F	145	148
G	160	155
H	151	136
I	158	166
J	148	149
K	181	175

The fraction of the total ionization current generated by those atmospheric showers which produced bursts greater than 80 particles in one chamber was determined by computation from the size-frequency distribution curve for one chamber given in Fig. 4. These data from Fig. 4 were first replotted to give the differential size-frequency distribution curve. This curve was then divided into K equal intervals taken along the abscissa, and the following sum was formed:

$$Q=\sum_{n=1}^{K} S_nN_nq_t, \tag{3}$$

where S_n = average number of particles per burst for the size interval n, N_n = average number of bursts per hour for interval n, q_t = charge per track as previously computed. These K intervals covered the range from 80 to 960 particles per burst. Q, then, is the total charge generated in one chamber per hour by showers producing bursts of more than 80 particles. The average ionization current caused by these showers is found by dividing this charge by the number of seconds in an hour. The current found in this manner was 2.88×10^{-15} ampere. It follows, then, that the fraction of the total ionization current caused by showers producing bursts of more than 80 particles was 1.4 percent. The inclusion of bursts of less than 80 particles in these computations may not increase the fraction of the total ion current due to showers to more than a few percent.

A further check of the reliable and consistent operation of the apparatus was made by determining the smallest burst distinctly observable on the trace. A burst containing approximately 30 particles could be detected at many places along the photographic trace. This fact illustrates that very few, if any, of the 80 particle bursts could have been overlooked in this investigation.

Measurements of bursts in unshielded ionization chambers are complicated by the fact that the very large number of cosmic-ray particles, not associated with showers, are subject to the usual statistical fluctuations. The number of these particles traversing the chamber during a given time interval may differ sufficiently from the average number to produce a relatively sudden deflection of the galvanometer string.[14] It is, then, necessary to construct the apparatus so that these statistical fluctuations can be easily distinguished from real bursts due to air showers. This differentiation was accomplished by making the collection time of the ions in the chamber as small as possible. This establishes a minimum value of the grid resistor R since the time constant (RC value) of the collecting system for the chamber must be long as compared with the collecting time of the ions. If this were not the case, the voltage signal, due to a burst, would be a function of the point in the chamber where the ions are formed.

Schiff and Evans[15] have given a formula for computing the standard deviation of a counting rate meter. This meter consists of a circuit for placing some charge q_1 per count on a condenser C which has a resistor R connected across it. The voltage built up across the resistor R will be a measure of the counting rate. The capacity of each ionization chamber in conjunction with the grid resistor of the FP-54 tube acted essentially as a counting rate meter, within the approximation that the charge generated in the chamber by each cosmic-ray particle is a constant. The formula given by Schiff and Evans for the standard deviation is applicable for the conditions which obtained in the chambers. This is:

$$\sigma = \frac{1}{(2RCn)^{\frac{1}{2}}}, \tag{4}$$

where σ = standard deviation in the voltage across grid resistor R, n = number of rays traversing the chamber per second, C = total input capacity of chamber and amplifier. Evaluation of this formula gives, for the chambers used here, $\sigma = 0.0089$, which corresponds to a deviation in the galvanometer deflection equivalent to that produced by a 60 particle burst. These variations had a long period and produced a continuous trace of an irregular character on the photographic film. These long period irregularities caused by this phenomenon were very seldom larger than the deflections due to 150 particle bursts. In contrast, the bursts were observed as very sharp discontinuities in this irregular trace. However, statistical fluctuations occurring within a time interval equal to the collecting time of the ions (0.4 sec.) could also produce rapid galvanometer deflections which might be mistaken for bursts due to showers.[14] The average number of cosmic-ray particles traversing the chamber in 0.4 sec. was approximately 170. The fluctuation equivalent to the standard deviation would then be 13 particles. The apparatus was not capable of recording a burst as small as this, but a fluctuation occurring within the collection time of the ions generated by a particular shower could reduce or increase the true size of a burst by the amount of this fluctuation. This means that a statistical fluctuation of ten particles would make an 80 particle burst appear as 90 particles, or 70 particles, depending on the direction of the fluctuation. The net result of these fluctuations is to change the slope and the absolute value of the size-frequency distribution curve for a single chamber, making the observed burst rate higher than the true rate. The equation describing this phenomenon, together with methods of determining the correction to be made, will be discussed at length in a paper now in preparation. The correction amounts to about 15 percent at the 80 particle size and decreases to less than 7 percent at the 320 particle size for the chambers used in this experiment. Undoubtedly, the number of observed coincidences will also be too high.

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[14] Evaluation of the formula given in Bennett, Brown, and Meyer, Phys. Rev. **47**, 437 (1935) for the burst rate caused by statistical fluctuations gives less than one 80-particle burst per year for the conditions of observation at Echo Lake.

[15] L. I. Schiff and R. D. Evans, Rev. Sci. Inst. **7**, 456 (1936).

The equation describing the relation between observed and true coincidence rates is yet to be solved. This phenomenon, which is important for small burst sizes, has been neglected in previous size-frequency distribution measurements. Both the chance burst-coincidence rates and the statistical fluctuations can be very much reduced by reducing the collection time of the ions in the chamber. For this reason the author feels that the data given in this paper for the smaller size bursts and at the larger separations of the chambers should be compared with data taken with an instrument of higher resolving power.

A possible source of error, giving rise to too many small burst coincidences at the smaller separations of the chambers, is the presence of slow, heavily ionizing particles. These particles are found in cloud chambers at high altitudes. It is doubtful if this could have an appreciable effect on the number of coincidences observed for several reasons. First, there was very little heavy material in the neighborhood of the chambers in which slow protons could be produced. Second, such heavily ionizing particles do not have sufficient range to traverse a path of 70 cm in argon and penetrate three ionization chamber walls. Third, the decrease in coincidence rate with increasing separation of the chambers is more rapid for the very largest sized bursts than for the smallest. The slow particles would rarely have an ionization density as large as 320 times the average for a single particle, or 500 times the minimum density of a single particle, and, hence, could not affect the larger size bursts.

DISCUSSION

If one assumes the lateral structure predicted by diffusion equations of the cascade theory, the data presented here constitute a direct experimental demonstration of the existence of extensive cosmic-ray air showers containing regions of high particle density which cover at least 100 square meters area. Some of the largest showers observed had a minimum density of 6000 particles per square meter over this 100 square meter area and, hence, contained at least 600,000 particles. In other cases, showers were found which had a minimum density of 9000 particles per square meter over an area of at least 15 square meters. Estimates, from the cascade theory, of the total energy of these showers, based on the assumption that they originate from primary particles at the top of the atmosphere, give a value of nearly 10^{17} ev which represents the highest energy so far reported.

All of the size-frequency distribution curves, Fig. 4, for bursts in a single chamber and for coincident bursts, are better represented by an exponential function than by a power law. The cascade theory, applied to showers originating at the top of the atmosphere from primary electrons having a power law spectrum, gives a size-frequency distribution function of a power law type for bursts in the single chamber. The statistical fluctuations which cause an error in the size of the small bursts cannot explain this discrepancy, since this error changes the slope and absolute values of the size-frequency distribution curve, but does not appreciably change the shape of the curve except for burst sizes smaller than 80 particles. Failure to record all the smaller bursts would result in a deviation of the experimentally determined size-frequency distribution curve away from the power law distribution and toward the exponential distribution. No appreciable number of the smaller bursts could have been overlooked; therefore, the frequencies of the small bursts cannot be expected to be too low. In fact, a considerable difficulty arises because the observed burst frequencies in a single chamber are very much higher than those computed on the basis of a cascade multiplication of electrons entering the earth's atmosphere and having an energy spectrum assumed by Euler[6] and Hilberry.[2]

The frequencies of coincident bursts as a function of separation of the chambers show, for all curves, a rapid decrease in frequency with increasing separation. This decrease is much larger than can be accounted for by the lateral density distribution of cascade showers started from the top of the atmosphere. The strikingly small extension of the high density region of the majority of the showers is shown by the curve in Fig. 4 labeled "zero separation minus 39 cm separation." This curve gives the size-frequency distribution of bursts in one chamber not accompanied by bursts of 80 particles or more in the other chamber, when the chambers are separated by a distance of 39 cm. This curve reveals that the majority of bursts in one chamber are not in coincidence with a burst in the other chamber. In most cases, even for bursts of several hundred particles in one chamber, no measurable coincident burst was found in the other. An extreme case of such an event was a burst of 960 particles traversing one chamber unaccompanied by as many as 30 particles traversing the other chamber. In this particular case, only 4 cm separated the outer walls of the two chambers (39 cm separation).

The results of this experiment strongly indicate the presence of showers with a very small extension of their high density region. Such showers most probably originate far below the top of the atmosphere, which means that they must be started by high energy electrons or photons of secondary origin. A possible process which could produce electrons at great depths below the top of the atmosphere is the disintegration of a mesotron of very short mean life. The existence of such mesotrons was proposed in the theory of nuclear forces.[16] Hamilton, Heitler and Peng[17] have used this type of mesotron to explain the lower energy soft component close to the top of the atmosphere.

Electrons of high energy could be produced far down in the atmosphere by such a process and might account for the narrow showers of high particle density observed at 10,650 ft. altitude. These showers, then, could produce a high density of particles in one chamber without having as high an energy as would be needed if the showers were started from the top of the atmosphere. This could also explain the high burst rate observed in a single chamber and the lack of a high coincidence rate at small separations of the two chambers.

The author is indebted to Dean A. H. Compton for his generous cooperation which made this work possible; to Professor Marcel Schein for much advice and for suggesting the problem; to E. W. Lewis for her continued help during the recording and analyzing of the data; and to Mr. I. Kalberg for his valuable help in constructing the galvanometers. He wishes to thank General Lawson and Captain Innes-Taylor for their generous assistance throughout the stay of the expedition at Camp Echo; and Mr. Cramner of the Denver Mountain Parks and Dr. Hyslop of the University of Denver for arranging the stay of the expedition in Colorado.

[16] Møller and Rosenfeld, Kgl. Danske Vid. Sels. Math.-Fys. Medd **17** (1940).

[17] Hamilton, Heitler, and Peng, Phys. Rev. **64**, 78 (1943).

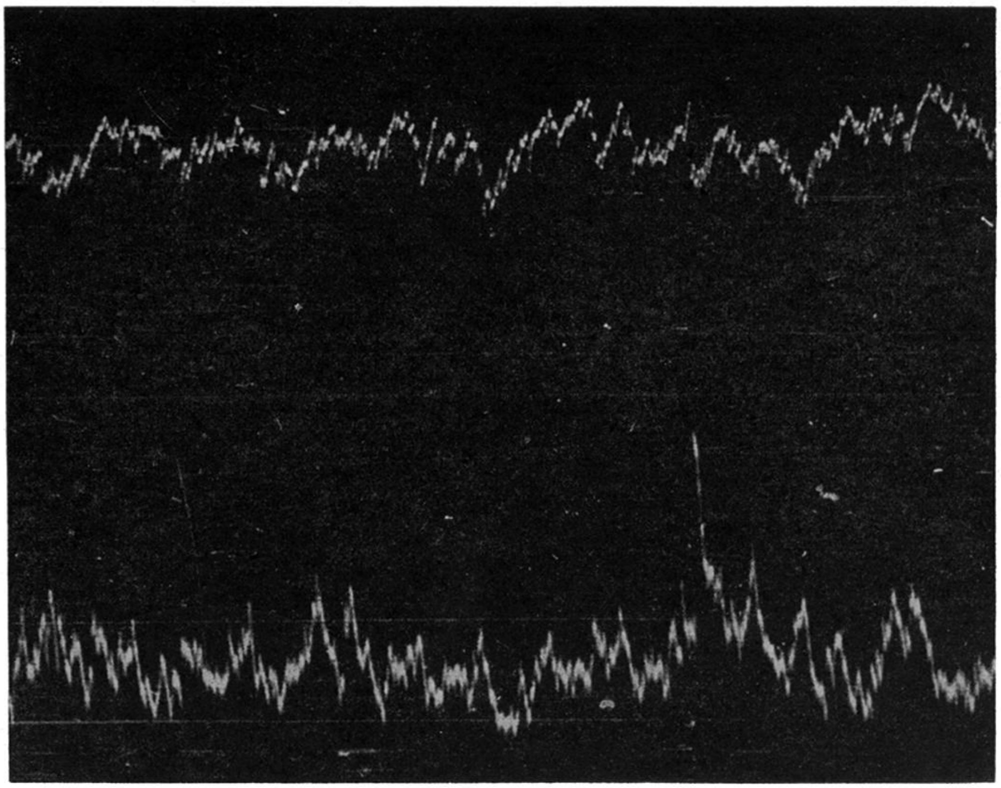

FIG. 2. A reproduction of a portion of the photographic trace taken at a chamber separation of four meters.