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

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

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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-

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** 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).

periments[3] and recent measurements made in a B-29 airplane by Schein, Yngve, and Kraybill[4] give convincing evidence that the hard component of the cosmic rays arises from primary rays which are mostly positively charged.

The situation with regard to the soft component is not so clear. Ground level measurements do not yield information about the primaries of the soft component because this component is so rapidly absorbed in the atmosphere. An important experiment performed by Johnson and Barry[5] in 1939 to measure the east-west asymmetry at high altitudes indicated that the primary cosmic rays are a mixture of positive and negative particles. At atmospheric pressures less than 5 cm of Hg the east-west asymmetry of the total radiation was found to be about 7 percent, whereas an effect of 60 percent was expected if the primary rays were exclusively positive. However, the balloon experiments of Schein, Jesse, and Wollan[6] and of Hulsizer and Rossi[7] indicate that the primary radiation contains almost no shower producing particles such as electrons. Taken together the two lines of evidence appear to require the existence in the primary radiation of penetrating negative particles which do not excite mesotrons but go into the production of the soft component.[8]

The present latitude effect and east-west asymmetry experiments were undertaken in order to help clear up this question of the origin of the soft component. A B-29 aircraft was available for the experiments, and although these planes cannot reach altitudes where it would be most desirable to do the experiment, their ceiling of 35,000 feet or more is high enough that the magnetic field sensitive primaries of the soft component can make their effects felt.

II. EXPERIMENTAL APPARATUS

The apparatus for the experiment consisted of six triple coincidence telescopes which were operated simultaneously and which could be rotated and tilted into various positions. The telescopes were arranged in three pairs. One telescope of each pair contained 14 cm of lead absorber and thus measured only the hard component. The other telescope was without lead shielding and thus measured the total cosmic-ray intensity except for those low energy particles which could not penetrate the brass walls of the counters. The soft component intensity was obtained by subtracting the hard from the total intensity.

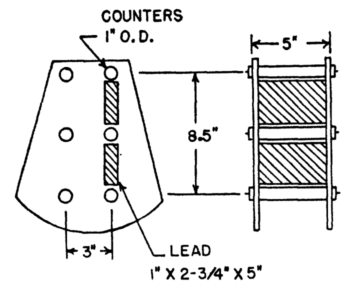

FIG. 1. Geometry of a counter telescope pair.

In the course of the experiments, telescopes of two different sizes were used. The geometrical arrangements of the two different telescopes are shown in Figs. 1 and 2. The small telescopes employed counters made of brass tubing with 0.030-inch walls. The tubing was one inch in outside diameter, and the exposed length of the central wire (0.003-inch diameter) was $3\frac{15}{16}$ inches. The extreme angular aperture of this unit was about ± 6 degrees by ± 24 degrees, but since the effective area of the telescope is smaller for the oblique angles, the average angle of the rays

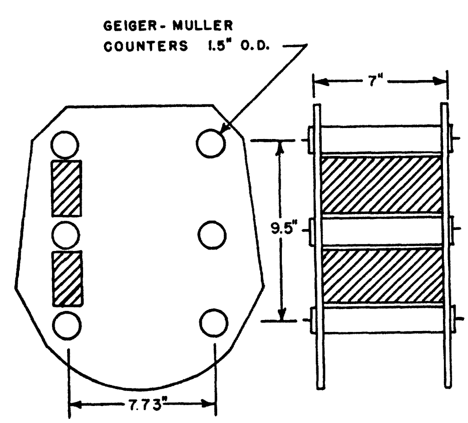

FIG. 2. Geometry of a large counter telescope pair.

[3] T. H. Johnson, Rev. Mod. Phys. **10**, 193 (1938).
[4] M. Schein, V. H. Yngve, and H. L. Kraybill, Phys. Rev. **73**, 928 (1948).
[5] T. H. Johnson and J. G. Barry, Phys. Rev. **56**, 219 (1939).
[6] M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **59**, 615 (1941).
[7] R. I. Hulsizer and B. Rossi, Phys. Rev. **73**, 1402 (1948).
[8] N. Arley, Phys. Rev. **70**, 975 (1946).

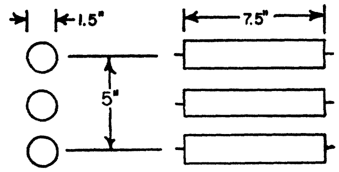

FIG. 3. Total radiation telescope with close geometry.

entering the telescope was much less than one-half of the values given. The counters of the larger telescopes were $1\frac{1}{2}$ inches in outside diameter with brass walls of 0.045-inch thickness. In this case the exposed length of the central wire was $5\frac{15}{16}$ inches so that the extreme angular aperture was about ± 9 degrees by ± 32 degrees. During the east-west experiments the telescopes were operated so that the best resolution was in the zenith angle.

For some of the latitude measurements on the vertical rays, the larger counters were used in a close geometry so that a larger solid angle was obtained. This geometry is shown in Fig. 3.

Experiments were also performed with a counter geometry which selected shower producing particles. For these experiments three of the larger size counters were placed in coincidence and arranged to form a triangle. In all of the shower measurements a $\frac{1}{2}$-inch layer of lead was placed above the top counter. The geometry of the shower arrangement is shown in Fig. 4.

The counters were filled with argon and a quenching vapor which in the small units was ethylene and in the large units was ethyl alcohol. The quenching gas was used in amounts of 10 to 15 percent, and the total pressure of filling was 10 cm of Hg.

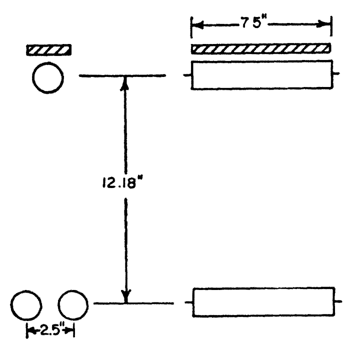

FIG. 4. Shower telescope.

Throughout most of the measurements the telescopes were used with an anticoincidence system in operation so that the background of coincidences due to showers was reduced. A coincidence of the three counters of the telescope measuring the hard intensity was not recorded if one or more counters of the associated telescope measuring the total intensity was discharged at the same time. Similarly, each one of the hard counters was in anticoincidence with the total telescope.

For some measurements the anticoincidence interconnection was removed. No anticoincidence was used with the telescope of Fig. 3 or the shower geometry of Fig. 4.

The resolving time of the coincidence circuits was about 7 microseconds, so that the rate of accidental triple coincidences was always less than 1 percent of the true rate and therefore negligible.

The calculated correction for loss in efficiency of a telescope due to the dead time of the individual counters was 4 percent in the case of the large telescopes at the highest altitude reached. This correction depends on the individual rates of the counters and therefore will not affect the measurement of the east-west asymmetry. The correction is most important in making measurements of intensity as a function of altitude. Some of these measurements were made with the present apparatus, but in this case the small telescope units were used and here the maximum correction is only about 2 percent.

The loss in coincidence counts due to the resetting time of the mechanical recorder was negligible in all cases except for the high altitude measurements made with the close geometry telescope of Fig. 3. In this case a correction was used which, at maximum, amounted to 3 percent.

III. MEASUREMENTS OF INTENSITY AS A FUNCTION OF ALTITUDE

The apparatus was operated successfully for 24 flights which were made during the period from February to July 1948. The total flying time was 160 hours, but the time spent at high altitudes in recording data was about 120 hours.

During the early flights, measurements of the vertical intensity of the hard and total components as a function of pressure altitude were carried out. These measurements were intended chiefly as a test of the apparatus, and were therefore not exhaustive. However, the results are of some interest in their own right so they are given in Tables I and II. The results as given include a correction for counter dead time which at the maximum altitude amounted to 2 percent. The small telescopes were used exclusively for these measurements.

Table I gives the number of counts per minute when the anticoincidence protection against showers was employed. The column headed "W" gives the probable error based on the total number of counts recorded, while the column "W_0" gives the probable error as computed from the consistency of individual determinations. The general agreement between W and W_0 indicates the absence of gross experimental inconsistencies. At altitudes 25,000 and 36,000 feet measurements were also taken with 7 cm of lead absorber.

Table II gives the results obtained from one of the telescope pairs after the anticoincidence connection had been removed. The counting rates here are 5 to 10 percent higher than the corresponding rates in Table I.

In Fig. 5 the data of Table I are compared with results obtained by other investigators. The solid curves of Fig. 5 represent the absolute vertical intensity of the hard and total components as compiled by Rossi.[9] Table I and not Table II is used for the comparison because protection against showers was employed in most of the measurements presented by Rossi. The material of the total telescope was 5 g per cm² of brass for Rossi's case and also 5 g per cm² in the present experiments. The filters used for the hard component were 14.6 and 14 cm of lead for Rossi's curve and the present measurements respectively. No attempt at an absolute comparison of the intensities has been made. The hard component intensity of the present experiments has been fitted to Rossi's curve at an atmospheric depth of 955 g per cm², and all the other values of Table I have been plotted relative to this point. It is seen that at the higher altitudes the results of Table I lie below Rossi's curves. This difference can be accounted for in part by the

TABLE I. Vertical counter data with anticoincidence.

Geomagnetic latitude 41°N.							
Pressure altitude feet	Atmos. depth g/cm²	Total rate C/min.	W C/min.	W_0 C/min.	Hard rate 14-cm Pb C/min.	W C/min.	W_0 C/min.
2,200	955	0.79	±0.005	±0.01	0.57	±0.005	±0.008
15,000	583	3.20	±0.075	±0.035	1.27	±0.05	±0.055
20,000	475	5.13	±0.08	±0.035	1.72	±0.035	±0.03
25,000	383	8.50	±0.06	±0.07	2.18	±0.03	±0.03
29,000	321	10.55	±0.20	±0.20	2.68	±0.10	±0.11
33,000	266	14.20	±0.23	±0.22	3.01	±0.10	±0.07
36,000	231	16.3	±0.17	±0.22	3.24	±0.10	±0.14
					7-cm Pb		
25,000	383	—	—	—	2.69	±0.11	—
36,000	231	—	—	—	5.00	±0.16	—

TABLE II. Vertical counter data with no anticoincidence.

Geomagnetic latitude 41°N.					
Pressure altitude feet	Atmos. depth g/cm²	Total rate C/min.	W C/min.	Hard rate 14-cm Pb C/min.	W C/min.
2,200	955	0.84	±0.012	0.57	+0.01
20,000	475	5.95	±0.18	—	—
25,000	383	9.00	±0.09	2.35	±0.05
29,000	321	11.14	±0.20	2.72	±0.10
33,000	266	15.20	±0.15	3.41	±0.07
36,000	231	17.60	±0.24	3.85	±0.10

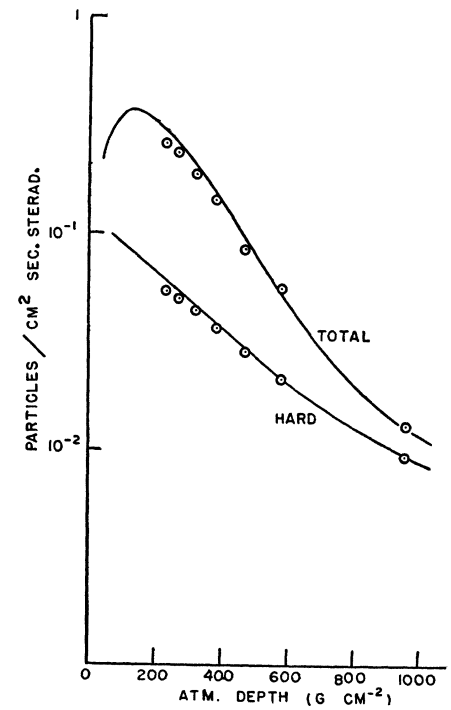

FIG. 5. Intensity of the total and hard radiation as a function of atmospheric depth. The solid curve represent the data compiled by Rossi (see reference 9). The points represent data taken with the telescopes of Fig. 1 where the hard component was filtered through 14 cm of lead and the absorber in the total telescope was 5 g per cm² of brass.

[9] B. Rossi, Rev. Mod. Phys. 20, 537 (1948).

TABLE III. Vertical intensity of showers, soft component, and total radiation at 2 different altitudes.

Pressure altitude feet	Atmos. depth	Shower rate geometry Fig. 4	Soft rate From Table I by subtraction	Total rate geometry Fig. 3	Total rate Table I
		Geomagnetic latitude 41°N. Plus and minus (Figures are probable error)			
2,200	955	0.195±0.008	0.22±0.007	9.60±0.06	0.79±0.005
25,000	383	5.46 ±0.10	6.32±0.07	105.4 ±0.05	8.50±0.06
Factor of increase:		28.0 ±1.3	29.0 ±1.1	11.0 ±0.1	10.8 ±0.1

TABLE IV. Counting rates at 25,000 feet as a function of geomagnetic latitude.

Geomagnetic latitude	Total C/min. 45°E	Total C/min. 45°W	Total C/min. Vertical	Hard C/min. 45°E	Hard C/min. 45°W	Hard C/min. Vertical	Showers vertical C/min.
7° to 11°N	11.2	13.85	25.9	3.32	4.55	6.91	4.72
Probable error:	±0.30	±0.32	±0.30	±0.15	±0.18	±0.15	±0.10
24° to 30°N	14.05	15.70	—	3.93	5.15	—	5.21
Probable error:	±0.19	±0.21	—	±0.10	±0.12	—	±0.10
30° to 36°N	15.32	16.55	—	4.67	5.52	—	5.37
Probable error:	±0.19	±0.21	—	±0.11	±0.12	—	±0.10
41°N	16.35	17.30	33.0	4.93	5.37	9.21	5.46
Probable error:	±0.13	±0.13	±0.22	±0.07	±0.07	±0.12	±0.10
47° to 53°N	17.1	17.9	36.6	5.65	5.43	10.0	5.50
Probable error:	±0.44	±0.37	±0.20	±0.26	±0.21	±0.11	±0.10
$(I_{47}-I_9)/I_{47}=$	0.35	0.23	0.29	0.41	0.16	0.31	0.14
Probable error:	±0.032	±0.027	±0.010	±0.053	±0.05	±0.019	±0.026

TABLE V. Counting rates at 33,000 feet as a function of geomagnetic latitude.

Geomagnetic latitude	Total C/min. 45°E	Total C/min. 45°W	Total C/min. Vertical	Hard C/min. 45°E	Hard C/min. 45°W	Hard C/min. Vertical	Showers C/min. 45°E	Showers C/min. 45°W
1°S to 5°N	21.6	27.6	37.8	4.87	7.19	7.72	—	—
Probable error:	±0.30	±0.35	±0.8	±0.15	±0.18	±0.37	—	—
13° to 19°	22.7	28.6	—	4.72	7.69	—	5.46	6.40
Probable error:	±0.45	±0.4	—	±0.21	±0.21	—	±0.17	±0.17
20°	23.3	29.4	—	5.30	7.57	—	—	—
Probable error:	±0.21	±0.26	—	±0.11	±0.12	—	—	—
31° to 37°	28.6	32.4	—	6.70	7.93	—	6.22	6.45
Probable error:	±0.45	±0.51	—	±0.12	±0.14	—	±0.12	±0.13
41°	33.7	35.6	55.0	7.92	8.63	12.47	6.56	6.95
Probable error:	±0.25	±0.24	±0.9	±0.12	±0.12	±0.40	±0.12	±0.13
$(I_{41}-I_2)/I_{41}=$	0.36	0.225	0.31	0.385	0.17	0.38	—	—
	±0.012	±0.012	±0.022	±0.024	±0.025	±0.044	—	—

latitude effect. The present experiments were done at 41 degrees north geomagnetic latitude, whereas the data comprising Rossi's curves were taken at geomagnetic latitudes north of 45 degrees.

Vertical measurements at 2200 and 25,000 feet were taken with the shower telescope of Fig. 4 and the close geometry telescope of Fig. 3. A comparison of these measurements with the points of Table I, which correspond in altitude, is given in Table III. The total intensity as recorded by the geometry of Fig. 3 shows about the same increase in going from 2200 to 25,000 feet as does the intensity recorded by the total telescope of Fig. 1. The shower intensity, on the other hand, increases by about the same ratio as the soft component. This is to be expected, in that the showers are produced chiefly by electrons which also make up the bulk of the soft component.

IV. MEASUREMENTS OF THE EAST-WEST ASYMMETRY AND LATITUDE EFFECT

Measurements of the east-west asymmetry were carried out at several different geomagnetic latitudes. Almost all of the measurements were made at pressure altitudes of either 25,000 or 33,000 feet and with the telescopes inclined at a zenith angle of 45 degrees.

It was unfortunately not possible to carry out the same type of flight plan in making all of the measurements. The plane was based at Inyokern, California, and by making flights from this base it was possible to make a series of measurements where the plane was flown back and forth (over a longitude range of 5 degrees) along the 41 parallel of geomagnetic latitude. Data about the point 34 degrees N geomagnetic latitude were obtained by making flights south from Inyokern along the coast of Lower California. In this case the results represent an average obtained over the range 31 to 37 degrees. Other measurements south of 34 degrees were made on a trip where the plane was flown to San Antonio, to Panama, and then south from Panama to the geomagnetic equator. The path was retraced for the return trip. Values of the east-west effect were measured enroute, but again the reported values represent averages over a range of latitudes. However, at Panama a flight was made under conditions similar to those which obtained at 41 degrees N. The plane was flown at 33,000 feet back and forth over a 5 degree range in longitude along the 20th parallel of geomagnetic latitude. Flights were also made north from Inyokern to the Canadian border in order to make more complete the range of latitudes covered by the experiment.

The geomagnetic positions have been obtained from the geographic positions by making use of the tables given by McNish.[10] The vertical and east and west counting rates as a function of geomagnetic latitude are given in Tables IV and V. The probable errors in each rate as determined from the number of counts recorded are also tabulated. At the bottom of each table the percent change of intensity over the range of latitudes is given. Because the measurements at 25,000 feet do not cover exactly the same range of latitudes as those at 33,000, care must be exercised in comparing the latitude changes at the different altitudes.

In making the measurements of Tables IV and V, the telescope pairs were always inclined in such a way that the hard telescope was underneath the total telescope. This precaution is necessary in order that showers produced by the vertical soft component in the lead absorbers are not likely to trip the total telescope. The large counter telescopes were used for most of these measurements, and consequently the rates in the tables are those recorded by the large units. In order to include in the tables the data recorded by the small telescopes, conversion factors between the large and small units were experimentally determined. At altitudes above 25,000 feet these factors were found to be 3.82 for the total telescopes and 4.08 for the hard telescopes. This difference in conversion factors for the total and hard telescopes is chiefly due to the fact that the counters of the large units have thicker walls than those of the small units so that the soft component is less able to penetrate the large telescopes.

Counting rates by the shower telescopes are also recorded in Tables IV and V. In taking the

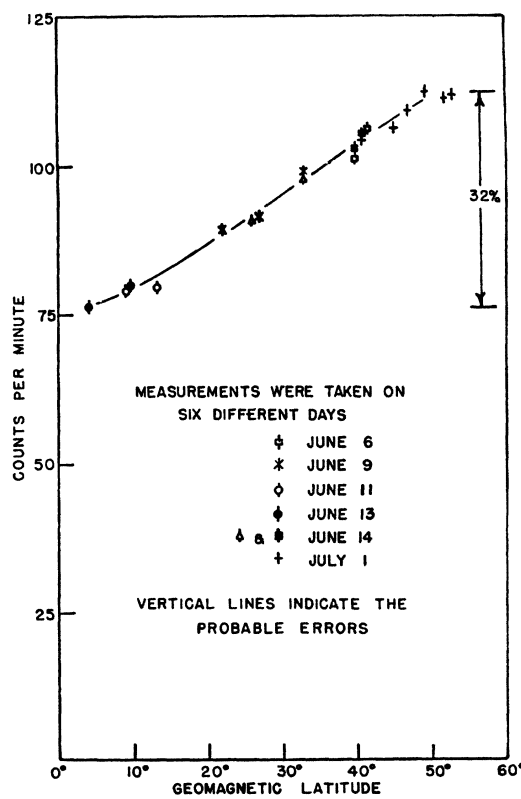

FIG. 6. Vertical total intensity as a function of geomagnetic latitude. The measurements were taken at 25,000-ft. pressure altitude with the telescope geometry shown in Fig. 3.

[10] A. G. McNish, Terr. Mag. 41, 37 (1936).

TABLE VI. East-west asymmetry at 25,000 feet, $A=2(I_W-I_E)/(I_W+I_E)$.

Geomagnetic latitude	Zenith angle =45° Amount of Pb	A	Probable error
7° to 11°N	0	0.21	±0.036
av. 9°N	14 cm	0.31	±0.062
24° to 30°N	0	0.11	±0.020
av. 27°N	14 cm	0.27	±0.036
31° to 37°N	0	0.08	±0.020
av. 34°N	14 cm	0.12	±0.033
41°	0	0.055	±0.012
	14 cm	0.085	±0.028

The point at 34°N is not quite the same as the 33°N data in Table IV.

TABLE VII. East-west asymmetry at 33,000 feet, $A=2(I_W-I_E)/(I_W+I_E)$.

Geomagnetic latitude	Zenith angle =45° Amount of Pb	A	Probable error
1°S to 5°N	0	0.24	±0.019
av. 2°N	14 cm	0.38	±0.040
	Soft (calc.)	0.20	±0.028
13° to 19°N	0	0.23	±0.024
av. 16°N	14 cm	0.48	±0.050
	Showers	0.16	±0.04
20°N	0	0.23	±0.013
	14	0.35	±0.026
	Soft (calc.)	0.19	±0.020
31° to 37°N	0	0.12	±0.018
av. 34°N	14	0.17	±0.024
	Soft (calc.)	0.11	±0.024
	Showers	0.035	±0.028
41°	0	0.055	±0.011
	14	0.085	±0.023
	Soft (calc.)	0.05	±0.016
	Showers	0.06	±0.027

shower rates no anticoincidence counters were used. For all the other data of Tables IV and V the anticoincidence system was in operation.

The statistical accuracy of the measurements given in Tables IV and V is not high enough to give the structure of the latitude effect in detail. The close geometry telescope of Fig. 3 was operated vertically during the latitude measurements at 25,000 feet, and here the counting rate is high enough that a rather precise curve of intensity *vs.* latitude can be drawn. This curve is shown in Fig. 6.

The east-west asymmetry coefficients for the various geomagnetic latitudes are given in Tables VI and VII. The asymmetry coefficient, A, has been calculated in the traditional manner,

$$A=2(I_w-I_e)/(I_w+I_e).$$

I_w represents the intensity of the radiation from the west, and I_e represents the intensity from the east at the same zenith angle. In most cases the asymmetry coefficients have been calculated from the data which comprise Tables IV and V. However, because of geometry differences, not all the data could be used for both purposes, and for this reason exact agreement should not be expected between the two sets of tables in all cases.

Except for the shower measurements, all of the data reported in Tables IV, V, VI, and VII were obtained with the anticoincidence system in use. Measurements to estimate the efficiency of the anticoincidence system in eliminating coincidences caused by showers were attempted by displacing one of the counters of a telescope so that at least two particles were required to produce a coincidence. With the anticoincidence system still in use, the counting rates with a counter thus displaced varied from four to ten percent of the count rate with a normal telescope. These measurements appeared to vary markedly with the distance that the out of line counter was removed from the telescope axis, and it was thought that knock-on particles rather than true showers were partially responsible for the residual counting rate with counters out of line. Because of this uncertainty, no shower correction beyond the use of the anticoincidence system has been employed in presenting the results. The asymmetry coefficients as reported in Tables VI and VII may be somewhat low on this account, but the error is probably less than 5 percent.

Some systematic errors which enter into the measurements have already been discussed. The most serious of these was the effect of counter dead time, and a calculated correction for this was applied before the results were tabulated.

Some of the more important of the nonsystematic sources of error in the experiment are the following:

1. The altitude of the plane is not constant. The pilots were asked to maintain the altitude within ±100 feet while measurements were being taken, and except for a few occasions when the air was rough, this tolerance was held. The altimeter was always set to read zero feet at a pressure of 76 cm of Hg so that the flights were made at constant pressure with a probable error in pressure altitude of less than ±100 feet. This

corresponds to an error in cosmic-ray intensity of about 0.5 percent. In any asymmetry experiment, east and west intensities were measured simultaneously so that the altitude error should be expected to be of little importance.

2. The zenith angle of the telescopes varies as the plane tilts or changes its attitude. A sensitive level bubble was used to indicate the correct angle. During flight the zenith angle oscillated by about 1 degree. However, the average position was checked and adjusted from time to time and it is not likely that the average angle over a flight was in error by more than $\frac{1}{3}$ degree. With the telescopes at a 45 degree zenith angle, a $\frac{1}{3}$ degree error makes a difference in east and west intensity of about 2.3 percent. At the northern latitudes the east-west asymmetry is only a few times this difference, and the error is serious.

3. The efficiencies of similar telescope units may be different or may change with time. In order to minimize this effect, computation of the asymmetry, A, has been made individually for each telescope. The individual results were then averaged to give the results in the tables. Whenever possible the telescopes were changed from east to west by turning the plane through 180 degrees. The geometry of the telescope, relative to the airplane, is thus allowed to remain constant during a series of measurements. This is important because the metal structure of the plane varies from place to place and can influence the intensity of the soft component.

In addition to the errors discussed above there is the uncertainty in the counting rates due to statistical fluctuations. In any one flight the probable error due to this cause is usually larger than the other errors discussed above. For this reason and because the calculation is easy, the probable errors given in Tables I to VII are those computed on the basis of the statistical fluctuations alone. It is thus to be expected that the true errors are often larger than the $\pm$ range given.

DISCUSSION OF THE EAST-WEST ASYMMETRY AND LATITUDE EFFECT

The east-west asymmetry results of Tables VI and VII all show positive values for the coefficient A. Since positive values of A indicate positive primary rays, it is possible to make the qualitative conclusion that the primary particles for both hard and soft components are mostly positive.

The amount of asymmetry increases rapidly as the geomagnetic latitude is decreased. At 33,000 feet from 41 degrees N to 20 degrees N the asymmetry of both hard and soft component increases by a factor of about 4.

The data also indicate that the asymmetry is increasing with altitude. However, the probable errors in each determination of A are such that the small increase from 25,000 to 33,000 feet cannot be accurately determined. Perhaps the best quantitative measure of the altitude increase can be obtained by comparing sea level measurements as made by other experimenters with the present 33,000-ft. measurements. Johnson's measurements[3] at geomagnetic latitudes 0 and 20 degrees north are suitable for an altitude comparison. At 76 cm of Hg pressure and with counter telescopes at 45 degree zenith angle, Johnson found the asymmetry, A, of the total radiation to be 0.14 at 0 degrees north and 0.07 at 20 degrees north. He also reports that filtering with 14 cm of lead reduces the asymmetry by about 25 percent, so the sea level asymmetry of the hard component is about 0.10 at 0 degrees north and 0.05 at 20 degrees north. From Table VII the corresponding coefficients at 33,000 feet are 0.38 and 0.35.

Because the details of the transition from primaries to secondaries are unknown, and because the absorption of the secondaries in the atmosphere is a complex process, it is difficult to make a direct quantitative comparison of the results with the theory. However, it is possible to make a rough analysis of the east-west asymmetry by comparing the coefficient, A, with the change in intensity observed in the latitude effect.

The latitude effect on the vertical rays does not depend on whether the primary particles are positive or negative and can thus be used to determine an "effective" energy spectrum for the primaries. This will be done by making the assumption that the cosmic-ray intensity at a certain point and under a certain thickness of air is inversely proportional to a power of the magnetic field cut off energy. (A power law distribution is assumed because this type of distribution has been found to give a fairly good representation of the primary energy spectrum.) The observed latitude effect is used to evaluate the power coefficient from the relation

$$\frac{I_{47}}{I_9}=\frac{E_{47}^{-\gamma}}{E_9^{-\gamma}}=\left(\frac{E_{47}}{E_9}\right)^{-\gamma}.$$

I is the radiation intensity of a given cosmic-ray component, and E is the critical energy. The subscripts refer to the geomagnetic latitude where each is evaluated.

A different value of γ will be determined for each of the different cosmic-ray components. The value of γ together with the east and west cut-off energies can then be used to predict what east-west asymmetry should result if the primary particles are all positive. To make the comparison valid, the air absorption in the east-west experiments and the latitude measurements should be the same. This is approximately true if the vertical latitude effect at 25,000 feet is compared with the 45 degree east west effect at 33,000 feet.

TABLE VIII. Comparison of the observed east-west asymmetry with values predicted from the latitude effect under the assumption that all primaries are positive.

Component	Latitude ratio I_{47}/I_9	γ	Predic. A 0°N	Obs. A 2°N	Predic. A 20°N	Obs. A 20°N
Hard	1.43	0.265	0.21	0.38	0.21	0.35
Soft	1.40	0.250	0.19	0.20	0.19	0.20
Showers	1.165	0.114	0.09	—	0.09	0.16*

* Observed at 16°N.

The comparison is made in Table VIII. The cut-off energies for the positions in question were determined from the curves given by Lemaitre and Vallarta[2] under the assumption that the primary particles are protons. Lemaitre and Vallarta have not determined cut-off energies for east and west rays at all latitudes, but they give values at 0° and 20°N which are suitable for comparison with the measurements at 2° and 20°N.* The energies involved are 3.5 Bev and 13.5 Bev for vertical rays at 47 degrees N and 9 degrees N, respectively, 24 Bev and 11 Bev for east and west rays at the geomagnetic equator, and 20 Bev and 9 Bev, respectively, for east and west rays at 20 degrees N. The latitude ratios were calculated from the data in Table IV, and the observed values of the asymmetry were taken directly from Table VII.

The comparisons in Table VIII show that the observed values of the east-west asymmetry are larger than the values predicted from the "effective" energy spectrum as determined from the latitude measurements, The predicted values are for the case where the primary particles are all positive so the discrepancy is in the wrong direction to be explained by including negative particles in the primary spectrum. The trouble probably is due to the rough theoretical methods that have been used because experimental refinements would tend to increase the observed value of A. For example, the finite aperture of the telescope used in the present experiments reduces the asymmetry from that which would be recorded by a telescope of infinitesimal aperture. Also any background of air showers which was not eliminated by the anticoincidence would decrease the observed value of A.

With regard to the assumptions involved in the calculation, it is by no means certain that the "effective" energy spectrum can be represented by a power law. Furthermore, the coefficient γ, which is evaluated for the energy range 3.5 to 13.5 Bev by the latitude effect, may not be valid for the range 9 to 24 Bev of the east-west experiment.

The assumption of an "effective" spectrum of an exponential type, $N=\text{constant}\times e^{-\alpha E}$, gives perhaps better agreement between the latitude effect and asymmetry measurements, but in view of the uncertainties mentioned above, this point should not be labored.

Fortunately, the experiment is quite sensitive to the number of negative particles in the primary radiation. If the number of negatives is $\frac{1}{4}$ of the total number, the east-west asymmetry is reduced by a factor of 2. In the case of the hard component and the showers, such a reduction would be completely out of line with experimental observations. The soft component, by the latitude effect comparison, has a relatively small asymmetry, so that the possibility of 25

* *Note added in proof:* Vallarta has recently published additional calculations suitable for the interpretation of the results of the present experiment [M. S. Vallarta, Phys. Rev. **74**, 1837 (1948)].

percent negative primaries for this component cannot be immediately rejected. However, the showers and the soft component are closely related, and it is likely not fortuitous that the east-west asymmetries of these components are about the same.

What has been called the soft component includes those electrons which are recorded in the shower measurements as well as slow heavy particles such as protons and mesotrons. It has already been concluded that the shower particles and the fast heavy particles (hard component) arise from primaries which are nearly all positive, and since the soft component is so closely related to these components, it is rather unlikely that $\frac{1}{4}$ of its primaries are negative. The following mechanism would account for the high latitude effect and the small asymmetry of the soft component without requiring the introduction of negative primaries. Suppose the low energy particles in the soft component are produced from primaries which are sensitive to the earth's magnetic field, so that the low energy secondaries contribute heavily to the latitude effect. If these low energy particles result from processes where the direction of the primary ray is not preserved by the secondary rays, they will not contribute full measure to the east-west asymmetry. This explanation requires that a large number of slow heavy particles be present in the cosmic rays at high altitudes. That a considerable number of such particles are to be found at altitudes of about 30,000 feet is shown by the cloud-chamber investigations of Adams *et al.*[11]

CONCLUSION

The experiments show that the large majority of the primary cosmic rays in the energy range 5 to 25 Bev are positively charged. The evidence is that the primaries of the shower producing radiation as well as those of the hard component are probably all positive. It could perhaps be argued that the results in the case of the soft component leave room for as many as $\frac{1}{4}$ of the primaries of this component to be negative, but the results on the shower producing particles make this conclusion unlikely.

To put the argument the other way around, it can be said that the experiments give no evidence whatever for the existence of negative particles in the primary radiation. As far as these experiments are concerned, it is not necessary to postulate the existence of negative protons or negative nuclei, and it is possible that a single type of primary particle is responsible for all of the cosmic-ray particles observed in the atmosphere.

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[11] Adams, Anderson, Lloyd, Rau, and Saxena, Rev. Mod. Phys. **20**, 334 (1948).