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APPENDIX

The small negative correction to the counts in column 3 of Table I is a correction for muon and electron contamination. As an example we calculate the correction for the first interval, at $K=34$ Mev.

The total pion track length in liquid hydrogen corresponds to 144.7 counts per millibarn. For a contaminant fraction f, the correction ΔN is $f\times144.7\times(d\sigma/dK)\Delta K$, where ΔK is 4 Mev for the interval under consideration, and $d\sigma/dK$ is the cross section for the contaminant to produce a 34-Mev δ ray.

The electron contamination f_e is 0.0065. The electrons have the beam momentum. The cross section, from Fig. 5, is 0.22 mb/Mev at $K=34$ Mev. Therefore ΔN_e is $0.0065\times144.7\times0.22\times4=0.83$. Similarly the monoenergetic component f_{ME} of the muon contamination contributes $\Delta N=0.015\times144.7\times0.13\times4=1.13$ counts.

The "unresolvably curvy" (UC) component of the muon contamination has a flat distribution in p_μ from 0.83 to $1.00p_\pi$, corresponding to radii of curvature from 150 in. to 180 in. in Fig. 7. For $p_\mu=p_\pi$ we have $K_m=104$ Mev; for $0.83p_\pi$, K_m is 73 Mev. Averaging Eq. (7) over p_μ from 0.83 to $1.00p_\pi$ yields an effective K_m of 87.4 Mev and a cross section $d\sigma/dK=(255/K^2)(1-K/87.4)$ mb/Mev, which is 0.13 mb at $K=34$. We therefore find $\Delta N=0.034\times144.7\times0.13\times4=2.56$. The total correction is $\Delta N=0.83+1.13+2.56=4.52$ counts to be subtracted from the 62 observed counts.

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Latitude Effect on Extensive Air Showers of Cosmic Rays*

SEINOSUKE OZAKI†
Laboratory of Nuclear Studies, Cornell University, Ithaca, New York
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The variation of air shower counting rate with latitude has been measured between 7° and 50°N at sea level. The observed showers have 10^6 charged particles on the average. Within the statistical accuracy, a few percent, no latitude effect on the intensity has been obtained.

INTRODUCTION

In the last several years, the directional distribution of extensive air showers, abbreviated as EAS, in the celestial system has been discussed[1–3] frequently, since this may reveal information about the origin and acceleration of cosmic rays and about the nature of the space through which they have travelled before reaching the earth. The observations for this purpose which were performed at sea level consist either of simply measuring the time variation of EAS, or of measuring the zenith and azimuth angles of EAS, knowing the arrival time at the observatory, and computing the directions in the celestial system. The distributions have turned out to be isotropic within the limits of reasonably probable fluctuations, which are less than 10^{-3} for the showers of 10^5 electrons and less than 10^{-2} even for showers of 10^7 electrons at sea level. However, it must be pointed out that these results apply mainly to the variation of the EAS intensity with right ascension, owing to the method of observation. There are a few measurements of the counting rate of EAS in the upper atmosphere[4] which indicate no latitude effect on the intensity of EAS from 0 to 60 degrees north geomagnetic latitude. But it is hard to conclude from this result that high-energy cosmic rays approach the earth uniformly with respect to declination, since the zenith angle distribution of EAS should be almost uniform down to 60 degrees in the upper atmosphere at pressures around 250 g/cm².

According to McCusker's analysis[5] of the directional

* Supported in part by the National Science Foundation.
† Now at Osaka City University, Osaka, Japan.
[1] J. Daudin, P. Auger, A. Cachon, and A. Daudin, Nuovo cimento **3**, 1017 (1956); J. K. Crawshaw and H. Elliot, Proc. Phys. Soc. (London) **A69**, 102 (1956); T. E. Cranshaw, W. Galbraith, S. Norris, and A. G. Parham, Oxford Conference, 1956 (unpublished); G. W. Clark, Phys. Rev. **108**, 450 (1957); P. Morrison, S. Olbert, and B. Rossi, Phys. Rev. **94**, 440 (1954); G. Cocconi, Nuovo cimento **3**, 1433 (1956).
[2] Clark, Earl, Kraushaar, Linsley, Rossi, and Scherb, Nature **180**, 353 (1957).
[3] P. Rothwell, B. Wade, and A. Goodings, Proc. Phys. Soc. (London) **A69**, 902 (1956).
[4] H. L. Kraybill, Phys. Rev. **76**, 1092 (1949).
[5] C. B. A. McCusker, Moscow Cosmic-Ray Conference, 1959 (unpublished), and Phys. Rev. **116**, 177 (1959). In the latter reference, there is an error in the utilization of the data of Rothwell *et al.* One need only examine the distribution in laboratory coordinates, given in reference 3, to see that there is no evidence for a north-south asymmetry of the primary cosmic rays; but an imprecise relation was used in translating the distribution into

distribution of EAS obtained by the Massachusetts Institute of Technology group,[2] the observed intensity ratio of EAS, R, is 20% bigger than that expected from the assumption of isotropic incidence of EAS at the earth. Here R is the proportion of the EAS that have declinations greater than the value of the latitude of the observing station. This conclusion, however, is inconsistent with the one deduced from the lack of time variations and is hard to understand on the basis of models of cosmic-ray origin which seem to be reasonable for other experiments on cosmic rays.

In this paper the variation of EAS intensity with latitude at sea level will be described. This is closely related to the variation with declination, since the zenith angle distribution of EAS at sea level decreases as $\cos^{8.3}\theta$.[6]

EXPERIMENTAL ARRANGEMENT

The experiment was performed on a vessel of the O. S. K. Line which plied between New York and Japan through the Panama Canal. The EAS were detected by four groups of Geiger counters placed on the deck of the vessel, one group being located at each corner of a rectangle, 20 meters on one side and 18 meters on the other. Each group of counters was divided into two counter trays named A and A', B and B', C and C', D and D', respectively. The total sensitive area of each tray was equal to 1500 cm². The pulses from each counter tray were sent to a central station, where they were put in the following coincidence circuits after being shaped to 2 microseconds width:

A, B, C, and D,

A', B', C', and D',

(A or A'), (B or B'), (C or C'), and (D or D'),

A, A', B, B', C, C', D, and D'.

The first three coincidences are fourfold and are named α', α'', and β, respectively. The last one is eightfold, named γ. No case was found where the counting rate of coincidence α' was not equal to that of α'' within the limit of statistical error throughout the run. This gave evidence of proper operation of the detectors in this observation. Besides, daily checks were made that all the counters and circuits were behaving properly and that there were no induction effects from the electric power of the vessel. The counters were located in CELOTEX boxes equipped with heaters to keep them at constant temperature.

RESULTS AND DISCUSSION

The coincidence rates described above were measured continuously from New York (latitude 41°N) to Yokohama, Japan (35°N), through the Panama Canal (7°N) and North Pacific Ocean (50°N). The results are shown in Fig. 1. All the plots in the figure have been normalized to the standard barometric pressure at sea level by assuming a barometric coefficient of 10% per cm Hg. This value was deduced from experimental results.[6,7] In some of the experiments the barometric coefficient appeared to depend slightly on the mean density of the detected showers but this variation is so small that it can be ignored in our case. The temperature coefficient of EAS also varies with the density of EAS and the spacing of counter trays. This coefficient, however, is on the order of 0.1% per degree for our counter geometry, which leads to less than 2% correction for the temperature difference (15°) between North Pacific Ocean and Panama Canal. The daily variation of temperature was very small owing to the observation being made on the ocean. Cocconi[8] has pointed out that the earth's magnetic field bends the electrons and positrons of EAS in opposite directions to stretch the lateral distribution into elliptical shape. Since the detection efficiency of EAS depends on the stretching factor, the counting rates should be affected by latitude through the change of the earth's magnetic field. However, this correction has been computed to be very small in our case. Another correction applicable to these

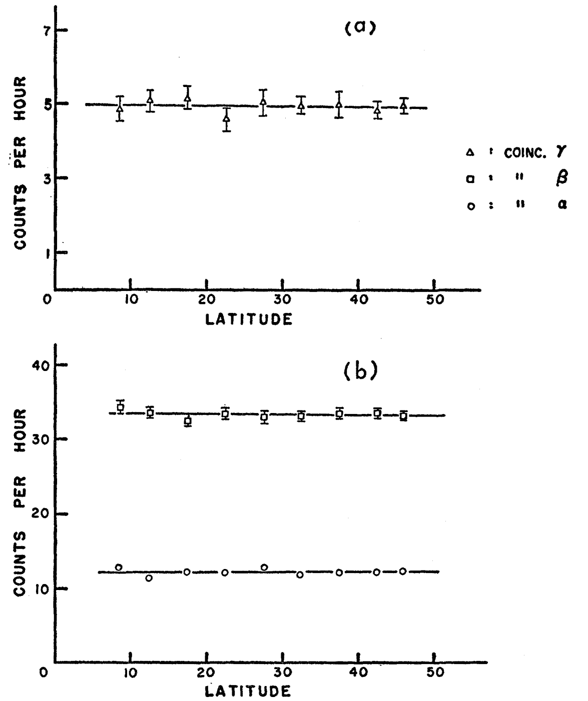

FIG. 1. The latitude variation of EAS intensity. α shows the average counting rate of the coincidences α' and α''. The statistical error of α is smaller than the circles.

the celestial coordinate system. McCusker's analysis was based on the erroneous translated distribution. This criticism does not apply to his interpretation of the MIT data.

[6] K. Greisen, *Progress in Cosmic-Ray Physics* (North-Holland Publishing Company, Ansterdam, 1956), Vol. III.

[7] J. Delvaille, F. Kendziorski, and K. Greisen, Moscow Cosmic-Ray Conference, 1959 (unpublished), and private communication.

[8] G. Cocconi, Phys. Rev. **93**, 646 (1954), and **95**, 1705 (1954).

data is the effect of centrifugal force acting on the air mass, which varies with latitude owing to the change of velocity of rotation. This correction is about 1.5% for our observations. The counting rates were actually corrected only for the barometric effect, since the other corrections are small and to some extent uncertain. Their effects are all in the same direction, however, and should tend to make the rates near the equator a few percent lower than those at 50° latitude.

Figure 2 shows the size spectrum of the EAS which are detected by the coincidence system. These curves have been computed from the number spectrum $F(\mathrm{N}) \sim \mathrm{N}^{-1.55}$ and the effective area around the counter array for the showers of a given size, which is estimated from the empirical formula[6] of the lateral distribution which fits the Nishimura-Kamata distribution well.

The straight lines of Fig. 1 are the best fit lines computed by the method of least squares and expressed as follows:

$$\text{for } \alpha, \quad I_\alpha = (12.20 \pm 0.33) + (0.0013 \pm 0.010)\lambda;$$

$$\text{for } \beta, \quad I_\beta = (33.66 \pm 0.43) - (0.011 \pm 0.013)\lambda;$$

$$\text{for } \gamma, \quad I_\gamma = (4.98 \pm 0.14) - (0.001 \pm 0.005)\lambda;$$

where λ is the latitude of the observation station.

From these distributions one can conclude that within an accuracy of a few percent in the region from 7 to 50 degrees north, the intensity of EAS involving about 10^6 charged particles does not depend on latitude. Since the zenith angle distribution of EAS can be expressed by $\cos^{8.3}\theta$, half of the EAS have zenith angles less than 20 degrees. Therefore the variation of EAS with latitude can be interpreted as a variation with declination. With the help of the results obtained by time variation experiments we may conclude that the primary cosmic rays having energy about 10^{16} ev are arriving at the earth isotropically (within a few percent). The protons of energy 10^{16} ev have a radius around 10^{19} cm in our galaxy due to the existence of the magnetic field of $10^{-5}-10^{-6}$ gauss on the average. Since this radius is much smaller than the thickness of the galaxy, these protons can be trapped within it, which can make the directional distribution isotropic. Furthermore, this kind of observation can not be affected by conceivable point sources of high-energy cosmic rays which cover only a small aperture, unless the total intensity from such a source is so large that it is several percent of the background arriving within an aperture of 0.5 steradian —the approximate angular aperture defined for our apparatus by atmospheric absorption. Therefore the isotropic incidence seems reasonable as a property of the cosmic rays of 10^{16} ev. This conclusion is inconsistent with McCusker's analysis of the MIT data, but in agreement with the cloud-chamber observations of Rothwell *et al.* on the arrival directions of the EAS. The present observations give stronger evidence of the absence of a declination effect, since the steep zenith angle dependence of EAS makes it difficult to deduce the declination distribution from data taken at a fixed station.

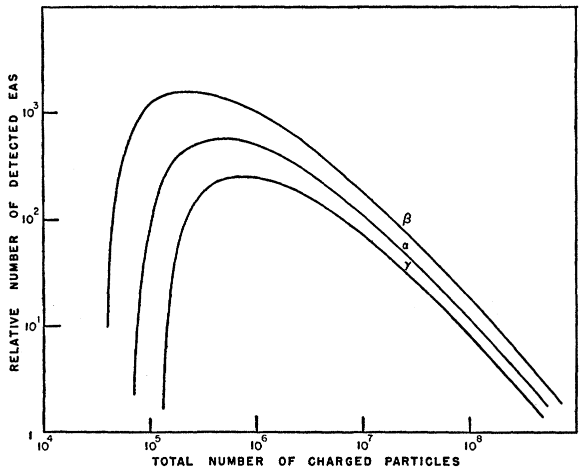

FIG. 2. Computed size spectrum of EAS observed by the coincidence systems α, β, and γ.

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