PHYSICAL REVIEW VOLUME 73, NUMBER 11 JUNE 1, 1948

The Directional Intensity of Cosmic Rays at Several Altitudes

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(Received February 9, 1948)

The vertical intensity and the intensity at inclined directions of the ionizing cosmic rays which penetrate 5 g-cm^{-2} of brass have been measured with a counter telescope at several altitudes between sea level and 10,700 meters.

I. INTRODUCTION

THE directional intensity of the ionizing cosmic rays has been measured accurately by Greisen[1] at altitudes between sea level and 4300 meters. The vertical intensity at greater altitudes, and at latitudes near 45°, has been measured by Pfotzer[2] and by Millikan, Neher, and Pickering.[3] Measurements have been made at greater latitudes by Johnson[4] and by Carmichael and Dymond.[5] Because of the rapid rate of ascent of the balloons used in these high altitude measurements the statistical errors are relatively large at intermediate altitudes. Also, there is little data available on the intensity at these altitudes for directions away from the vertical. When a B-29 aircraft was made available to this laboratory for other work in cosmic rays, it was thought advisable to make use of the remaining space for some measurements of this kind.

II. THE APPARATUS

The apparatus consisted of a simple counter-telescope and a coincidence circuit. The telescope was composed of seven identical Geiger-Mueller counter tubes held by a light frame in the arrangement indicated in Fig. 1. Two tubes connected in parallel were used for each of the three trays, marked 1, 2, and 3, of the telescope proper. The remaining "tray," the single tube marked 4, was used to determine the effect of side showers on the measurements. The frame held the tubes fixed relative to each other, but the assembly could be tilted about an axis parallel to the axes of the tubes so as to vary the angle θ in the figure. No part of the frame was within the solid angle subtended by the telescope.

Each counter tube was made of a brass cylinder 30 cm long, 2.54 cm in outside diameter, and with an 0.08 cm thick wall. The active part of the central electrode was an 0.008-cm tungsten wire 25.4 cm long. The tubes were filled to a total pressure of 10 cm of mercury with a self-quenching mixture: 90 percent, argon and 10 percent ethanol. The tubes had plateaus longer than 200 volts and were operated between 50 and 75 volts above the thresholds. Under these circumstances the spontaneous time lags were less than 0.7 μsec. for 0.999 of the discharges, and the inoperative time after each discharge was about 1.5×10^{-4} sec.

The four trays of the telescope were connected to a coincidence circuit which recorded simultaneously threefold coincidences (1, 2, 3) and (1, 4, 3), and fourfold coincidences (1, 2, 3, 4). The (1, 2, 3) coincidences were counted by a scale-of-8 and mechanical register; the other two, by registers directly. A scale-of-16 and register could be connected so as to record the discharges of any individual tray or the twofold coincidences between any pair of trays. The resolving time of all the coincidence circuits were 0.7 μsec. The recovery time of the coupling circuits between the tubes and the coincidence circuit, and of the scaling circuits was 20 μsec. and was, therefore, negligible compared with the recovery time of the G-M tubes. The mechanical registers would count successive events which were separated by more than 0.1 sec.[6]

III. THE MEASUREMENTS

The telescope was operated at sea level in Cambridge 3 meters below a 2 cm thick wooden

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[1] K. Greisen, Phys. Rev. **61**, 212 (1942).

[2] G. Pfotzer, Zeits. f. Physik. **102**, 23 (1936).

[3] R. A. Millikan, H. V. Neher, and W. H. Pickering, Phys. Rev. **63**, 234 (1943).

[4] T. H. Johnson, Phys. Rev. **54**, 151 (1938).

[5] H. Carmichael and E. G. Dymond, Nature **141**, 910 (1938).

[6] A detailed description of the circuits used will be published elsewhere.

roof. The measurements at all other altitudes were made in the rear pressurized cabin of a B-29 aircraft about 10 cm below the top of the fuselage, at a place where the average thickness of material above the telescope was about 1 g-cm^{-2} of light material. Five flights were made during January and February, 1947. The flights consisted usually of two periods at each of two different pressures. All flights were made at the same latitude (approximately 53° N mag.) and with the axes of the G-M tubes heading east-west. The telescope was inclined either north or south. During each period, at a given altitude, the telescope was operated vertically and at one other angle. For each angle, the counting rate in one tray and the twofold coincidence rates (1, 2), (1, 3) (1, 4), and (2, 4) were obtained as well as the threefold and fourfold coincidence data. The data from the several flights at the same pressure were self-consistent.

The threefold and fourfold coincidence data are given in Table I according to pressure and angle. The first and second columns give the pressure and approximate altitude at which the data were taken, the third, the zenith angle (θ of Fig. 1). In the fifth, sixth, and seventh columns are the data for the number of (1, 2, 3), (1, 4, 3), and (1, 2, 3, 4) coincidences obtained in all corresponding runs, the combined duration of which is given in the fourth column.

TABLE I. Threefold and fourfold coincidence data.

Pressure (g-cm^{-2})	Approx. alt. (meters)	Zenith angle	Duration (minutes)	Number of coincidences (1, 2, 3)	(1, 4, 3)	(1, 2, 3, 4)
250	10700	0°	62	14888	609	242
		60°	56	4564	240	107
390	9100	0°	45	8560	354	149
		30°	87	13152	452	199
310	7600	0°	171	21928	868	380
		30°	49	4752	185	86
		60°	72	2368	122	45
610	4300	0°	96	3656	133	71
		30°	121	3280	133	68
		60°	153	1288	80	45
1030	0	0°	7955	739120	1325	583
		30°	3445	23304	397	172
		60°	2305	5000	144	72

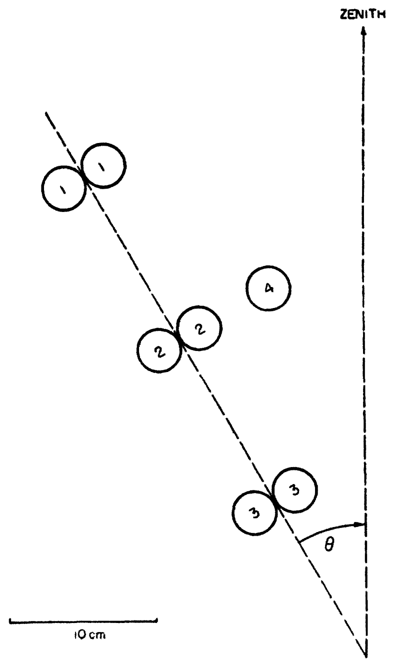

FIG. 1. Arrangement of the counter-telescope.

IV. THE CORRECTIONS AND RESULTS

The counting rates which one obtains from Table I are somewhat in error because of accidental coincidences and because of losses resulting from the recovery time of the G-M tubes. The correction to the (1, 2, 3) coincidence rate caused by accidental coincidences is given approximately by

$$S=-4\tau[\{1,2\}-I]\cdot[\{1\}-I],$$

where τ is the resolving time of the coincidence

TABLE II. Corrected counting rates for threefold and fourfold coincidences with $\theta=0$.

Pressure (g-cm^{-2})	Corrected counting rates (min.$^{-1}$) (1, 2, 3)	(1, 4, 3)	(1, 2, 3, 4)
250	244±2	9.9±0.4	4.1±0.3
310	193±2	8.0±0.4	3.4±0.3
390	129±1	5.1±0.2	2.2±0.1
610	38.2±0.6	1.39±0.12	0.74±0.09
1030	9.31±0.03	0.167±0.004	0.073±0.003

TABLE III. Angular dependence of threefold and fourfold coincidence rates; the ratios (counting rate at θ)/(counting rate at 0°) are tabulated.

Pressure	$\theta=30°$			$\theta=60°$		
(g-cm^{-2})	(1, 2, 3)	(1, 4, 3)	(1, 2, 3, 4)	(1, 2, 3)	(1, 4, 3)	(1, 2, 3, 4)
250	—	—	—	0.40	0.44	0.49
310	0.79	0.67	0.70	—	—	—
390	0.76	0.74	0.82	0.26	0.33	0.28
610	0.71	0.70	0.75	0.22	0.37	0.39
1030	0.73	0.69	0.69	0.23	0.38	0.43

TABLE IV. Vertical intensities of ionizing particles of range greater than 5 g-cm^{-2} of brass.

Pressure (g-cm^{-2})	Relative intensity	Absolute intensity (sec.$^{-1}$-cm^{-2}-steradian^{-1})
250	(26.2±0.21)	(0.280)
310	20.7±0.25	0.222
390	13.9±0.10	0.149
610	4.10±0.07	0.0439
1030	1.00	0.0107

circuit, $\{1\}$ is the counting rate in tray 1 and in tray 3, $\{1, 2\}$ is the rate of (1, 2) and of (2, 3) coincidences, and I is the observed rate for threefold coincidences (1, 2, 3). The correction to the observed (1, 2, 3) coincidence rate due to the counter dead time is given approximately by

$$E = +Ir[\tfrac{3}{2}\{1\} - \tfrac{1}{2}\{1, 2\} - \tfrac{11}{16}I],$$

where r is the dead time of a counter tube and the other symbols are as above. At all altitudes the correction E is much larger than S. At the highest altitude the combined correction, $E+S$, was, for $\theta=0$, +1.7 percent of the observed rate and at sea level +0.1 percent. Similar corrections were made to the rates for $\theta=0$ of threefold coincidences (1, 4, 3) and fourfold coincidences. In all cases these corrections were less than 2 percent. The corrected counting rates for threefold and fourfold coincidences with $\theta=0$ are given in Table II. The errors indicated are the statistical standard deviations.

It will be seen from Table II that the (1, 4, 3) coincidence rate is 2 percent of the (1, 2, 3) rate at sea level and about 4 percent at all other altitudes, and that the (1, 2, 3, 4) rate is 1 percent of the (1, 2, 3) rate at sea level and 2 percent at other altitudes. Part of this difference between the sea level and high altitude ratios may be due to the different location of the solid material above the counters in the two cases (see above). No attempt has been made to correct the (1, 2, 3) coincidence rate for the effect of side showers. Since such a correction would be only a fraction of the (1, 4, 3) coincidence rate, neglecting this correction can cause at most a 2 percent error in the intensities relative to sea level.

Since the instrumental corrections are small and essentially independent of θ, they have not been computed for angles away from the vertical. The ratios of the observed threefold and fourfold coincidence rates for $\theta=30°$ and $\theta=60°$ to those for $\theta=0$ are given in Table III. It is evident that the rate for threefold coincidences (1, 2, 3) exhibits a $\cos^2\theta$ dependence at all altitudes except the highest. The θ-dependence of the side coincidences appears to be only a little less sharp than $\cos^2\theta$. This, and the altitude variation shown in Table II, show that the side coincidence rate is at all altitudes approximately proportional to the soft component in the beam, and is therefore not due to large air showers but probably to small showers of local origin.

Since the angular dependence of the (1, 2, 3) coincident rate is independent of altitude up to 9100 meters, our data for $\theta=0$ represent correctly to that height the altitude variation of vertical intensity of the total ionizing component despite the large solid angle of the apparatus. The vertical intensities relative to the sea level intensity are given in the second column of Table IV. From an analysis of the available data, Rossi[7] concludes that the best value for the absolute intensity at sea level of particles from the vertical which penetrate 5 g-cm^{-2} of brass is 1.07×10^{-2} sec.$^{-1}$ cm^{-2} steradian^{-1}. This absorber thickness corresponds with that of the telescope used in the present experiments.

Using the above figure for the vertical intensity at sea level, one gets the absolute intensities given in the third column of Table IV. It is probable that the figures given in Table IV for a pressure of 250 g-cm^{-2} are a little large if the angular dependence is indeed different at that altitude.

ACKNOWLEDGMENTS

The author is indebted to Professor B. Rossi for suggesting and guiding this research. The work described was supported in part by the Office of Naval Research. The B-29 used for the measurements at high altitudes was provided by the U. S. Army Air Force.

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[7] B. Rossi, Rev. Mod. Phys. (to be published).