The Cosmic-Ray Intensity Above the Atmosphere at the Geomagnetic Equator*

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By means of G-M counter telescopes in an Aerobee sounding rocket fired from the USS Norton Sound, total charged particle cosmic-ray intensity above the atmosphere has been measured at the geomagnetic equator. An empirical zenith angle (θ) dependence of directional intensity, averaged over all azimuths, is found to be $j(\theta)=0.028(1+0.6\sin\theta)$, in which $j(\theta)$ is in absolute units (sec. cm^2 steradian)$^{-1}$. The deduced *vertical* intensity 0.028/sec./cm^2/steradian is thought to be most nearly free of atmospheric albedo and, therefore, to be our best estimate of an upper limit for the primary intensity of charged particles of energy greater than 14 Bev (for protons). A comparison is made with previous results at geomagnetic latitude 41°N.

THREE Aerobee sounding rockets[1] have recently been fired from the USS Norton Sound in a joint expedition of this Laboratory and the U.S. Navy. The present note[2] briefly reports the total cosmic-ray intensity above the atmosphere as determined with a set of four threefold G-M telescopes carried to about 105 km altitude by Aerobee A-10. This firing was conducted on March 17, 1949, on the geomagnetic equator about six hundred miles off the coast of Peru.

One pair of crossed wide angle telescopes AOB, XOY was mounted so that the axes of the respective telescopes were inclined 45° to the rocket axis and at right angles to each other (Fig. 1a). As in previous work,[3] counts from AOB, XOY, AOB (X and/or Y), XOY (A and/or B) were telemetered. The second pair of telescopes PQR, SQT, with multiple event channel PQR (S and/or T), is shown in Fig. 1b.

The orientation of axes fixed in the rocket was determined by the combination of a magnetometer and a set of sixteen photoelectric cells, using the geomagnetic field and the sun's rays, respectively, as reference vectors.

A continuous telemetered record without breaks was obtained from -120 sec. to $+317$ sec. by combining the records of two independent receiving stations.[4]

TABLE I.[a] High altitude plateau data (60–210 sec.).

(1) AOB (total)	260 counts	(6) PQR (total)	161 counts
(2) AOB (X or Y)	48	(7) SQT (total)	189
(3) XOY (total)	271	(8) PQR (S or T)	23
(4) XOY (A or B)	43	(9) $PQRST$	19
(5) $XOYAB$	31		
Rate of telescope AOB, less all recorded multiple particle events 1.21 ± 0.06 counts/sec.		Total rate of telescope PQR 1.07 ± 0.06 counts/sec.	
Rate of telescope XOY, less all recorded multiple particle events 1.31 ± 0.06 counts/sec.		Total rate of telescope SQT 1.26 ± 0.06 counts/sec.	
Average net rate per telescope $N_{AOB,XOY}=1.26\pm0.04$ counts/sec.		Rate of telescope PQR, less all recorded multiple particle events $N_{PQR}=0.79\pm0.05$ counts/sec.	

[a] Errors given in this report are statistical probable errors.

Table I summarizes data in the flight period 60–210 sec. (all above the appreciable atmosphere), during which the axis of the rocket described a rather complicated motion but was tilted about 15° from the vertical in a southwesterly direction on the average and did not deviate more than 30° from the vertical at any time. The roll rate of the rocket about its longitudinal axis was accurately constant with a period of 3.53 sec.

The ratio of "multiple" to "single" events is similar to, but slightly less than, the ratio at $\lambda=41°$N,[3] with nearly identical equipment.

As discussed in reference 3, the guarding of the telescopes is believed to be quite efficient and there is very little material in the path of a particle whose trajectory lies within the solid angle of the telescopes. Therefore, the *net* rate of the telescopes has been taken to yield the true charged particle intensity.

The geometric factor for AOB, XOY telescopes for uniform intensity over their apertures is $N/e^3j=31.7$ cm^2-steradian. Using this factor and making the minor corrections for intrinsic inefficiency, deadtime, and accidentals, we find the time-averaged directional intensity $j_{AOB,XOY}=0.0410\pm0.0014$/sec./cm^2/steradian. Similarly, using the uniform intensity geometric factor,[5] $N/e^3j=22.7$ cm^2-steradian for PQR, we find a time-averaged directional intensity $j_{PQR}=0.0355\pm0.0024$/sec./cm^2/steradian. Unfortunately, events SQT (P or R) were not recorded. But, if there is made the reasonable supposition that the number of such events is equal to the number of PQR (S or T) events, then we have the provisional value $j_{SQT}=0.0440\pm0.0026$/sec./cm^2/steradian.

The axis of telescope PQR was at an average zenith angle θ of about 15° during the data period considered. However, the above-calculated intensity j_{PQR} does not correspond to $\theta=15°$ because of the very wide acceptance angle in the plane of the G-M tube axes and because of apparent non-uniformity of intensity within this angle. When proper account is taken of the angular opening of PQR, an empirical zenith angle dependence

* Supported by the Navy Bureau of Ordnance under Contract NOrd 7386.

[1] Van Allen, Fraser, and Floyd, Science **108**, 746 (1948).

[2] A preliminary discussion was given at the Echo Lake Conference (June, 1949).

[3] Gangnes, Jenkins, and Van Allen, Phys. Rev. **75**, 57, 892 (1949).

[4] Operated by Mr. R. F. Ohlemacher and associates of the New Mexico College of Agriculture and Mechanic Arts and the U.S. Naval Unit, White Sands Proving Ground, New Mexico.

[5] H. E. Newell, Jr. and E. C. Pressly, Rev. Sci. Inst. **20**, 568 (1949).

of directional intensity, averaged over all azimuths, of

$$j(\theta)=0.028(1+0.6\sin\theta) \quad (1)$$

is found to yield good accord with all the experimental results. Equation (1) gives an approximate vertical intensity of charged particles above the atmosphere at $\lambda=0°$ of

$$j(0°)=0.028/\text{sec.}/\text{cm}^2/\text{steradian}.$$

It is thought quite unlikely that this value differs from the true vertical intensity by as much as 15 percent.

It is of particular interest to compare these results with corresponding ones[3,6] at White Sands, New Mexico ($\lambda=41°$N). See Table II.

The fact that the "average" upper hemisphere intensities deduced from the single counter data are larger than those deduced from the telescope rates, is thought to be due to three principal reasons: (a) From a typical altitude of 90 km, the "top" of the atmosphere (55 km) lies at a dip angle of six degrees below the horizontal. Thus, the single counter is exposed to radiation over appreciably more than one hemisphere, even in the absence of atmospheric albedo. The "dip angle" radiation contributes to the counting rate of a telescope only in the special case in which the telescope includes such directions within its aperture.

(b) A more-or-less vertical single counter presents its greatest effective area horizontally—from which direction there is the maximum intensity.

(c) Any soft charged radiation present above the atmosphere need penetrate only the missile skin and one counter wall in order to register in a single G-M counter. In the telescopes which we have used, penetration of at least five counter walls is necessary in order to register a coincidence. A single counter is also much more susceptible to moderate energy γ-rays than is a telescope.

TABLE II. Comparison of intensities above the atmosphere at two geomagnetic latitudes.

Geomagnetic latitude \ Approximate zenith angle	0°	45°	"Average' intensity from single G-M counter data
0°	0.028	0.041	0.053
41°N	0.070	0.109	0.13
Ratio	0.40	0.38	0.41

In addition to Table II there may be noted the latitude ratio 0.36 of multiple particle events in the array *AOBXY*. No cosmic-ray phenomena have been reported in the literature to exhibit a more rapid experimental latitude dependence over this range of latitude than do our intensity data reported here.

We find a crude value of vertical intensity at the Pfotzer maximum of $0.13/\text{sec.}/\text{cm}^2/\text{steradian}$ at $\lambda=0°$.

Insofar as the vertical intensity above the atmosphere may be taken as proportional to the primary intensity, the two values 0.028 at $\lambda=0°$ and 0.070 at $\lambda=41°$ can be used to calculate the exponent of an assumed power law primary spectrum. The result for the differential number spectrum is $E^{-1.9}$, considerably flatter than otherwise deduced.

We are especially indebted to Captain T. A. Ahroon,

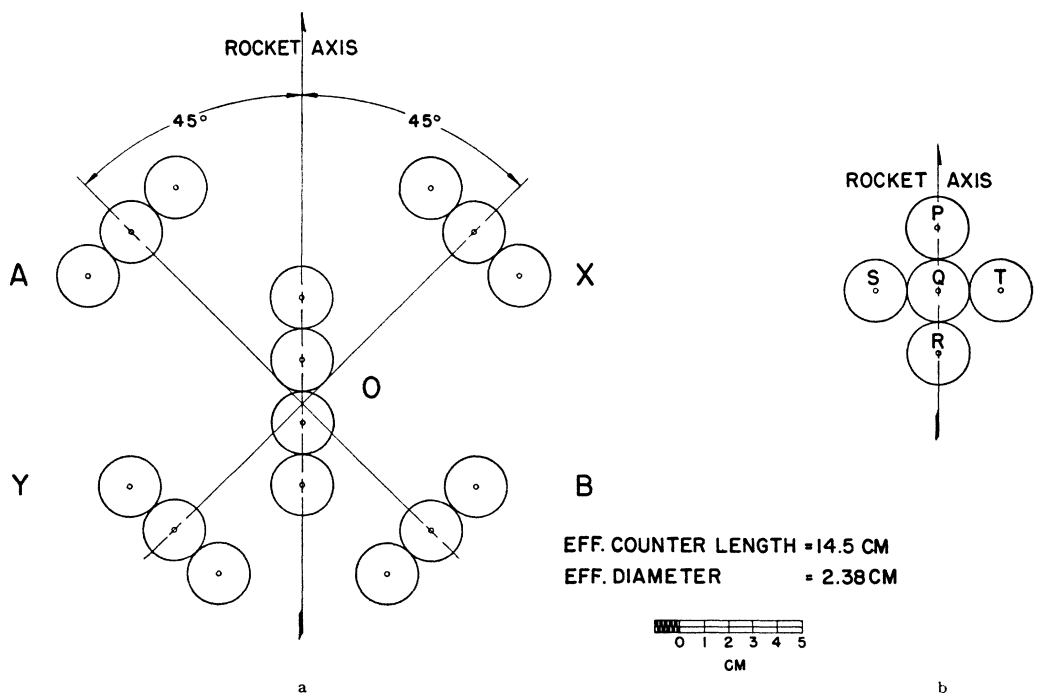

FIG. 1. Counter telescope arrangements.

[6] J. A. Van Allen, Echo Lake Conference (June, 1949). S. F. Singer, Echo Lake Conference (June, 1949).

USN, and the other officers and men of the USS Norton Sound for the conduct of the expedition and the rocket firing.

Added in proof: A check on the validity of the empirical Eq. (1) above is had by calculating the counting rate of a single G-M counter with axis vertical above the atmosphere. This rate is $\int_0^{90°} j(\theta)\cdot A(\theta)\cdot 2\pi \sin\theta d\theta$, in which $j(\theta)$ is given by Eq. (1), and $A(\theta)$ is the projected area of the cylindrical counter. The result for the counter used is 8.8 counts/second. The difference between this value and the observed counting rate 9.7 ± 0.2 counts/sec. is reasonably attributable to reason (c) above and perhaps to lack of accuracy in (1).

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The Effect of Hydrostatic Pressure on the Curie Point of Barium Titanate Single Crystals*

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The influence of hydrostatic pressure on the Curie temperature of $BaTiO_3$ single crystals has been investigated. With increasing pressure a linear shift of the Curie point towards lower temperature is observed with a slope of -5.8×10^{-3} degree/atmos. This information allows us to calculate the change of the specific heat and of the compressibility at the Curie point according to Ehrenfest's relation. Thus it is possible to relate the pressure effect to the change of the lattice constant. The decrease of the Curie temperature with shrinking lattice constant is nearly the same as that observed when Sr ions are substituted for Ba in the titanate crystal. In addition, measurements have been made on the influence of pressure on the first order transition point near 0°C.

INTRODUCTION

THE research of this laboratory on the properties of barium titanate[1-6] has the long-range objective of arriving at an understanding of the mechanism of ferroelectricity. The relatively simple perovskite structure of $BaTiO_3$ and of the related columbates and tantalates[7] offers an easier access to this problem than the complex structure of the other two ferroelectric groups, rochelle salt and the alkali phosphates and arsenates.

Barium titanate is cubic above the Curie point (120°C). One question of prime importance is to learn how the Curie temperature, that is, the onset of spontaneous polarization, depends on the lattice parameters. The lattice constant can be reduced by hydrostatic pressure, and a shift of the Curie point would be expected. Arguments can be presented for predicting a shift in either direction. Under pressure, the lattice dimensions prevailing at the normal Curie point are realized at higher temperature, hence the Curie temperature may be raised. *Vice versa*, the successive replacement of barium ions by strontium ions reduces the lattice constant and moves the Curie point downwards, hence pressure may lower the Curie temperature. The results given in the present paper decide this question experimentally.

APPARATUS

The pressure apparatus* (Fig. 1) consists of a pressure generator and a crystal chamber interconnected by a steel capillary. Hydrostatic pressures up to 5000 atmos. were reached by inserting the generator in a standard hydraulic jack. The temperature in the crystal holder could be adjusted from that of liquid air through the Curie region up to *ca.* 150°C, made possible by using silicone oil as the hydrostatic pressure liquid. The behavior of the Curie point was determined by measuring the dielectric constant as a function of temperature and pressure at 10 kc. A thermocouple, inserted in a hole of the crystal holder casing about 2 mm from the crystal, served as the temperature control and allowed the measurement of relative temperature changes with a high degree of reproducibility (0.1°C).

Dependence of the Curie Temperature on Hydrostatic Pressure

In contrast to the behavior of rochelle salt, for which Bancroft[8] found a shift of the Curie point to higher temperatures with increasing pressure, we found the opposite behavior for $BaTiO_3$ single crystals. Up to

* Sponsored by the ONR, the Army Signal Corps, and the Air Force under ONR Contract N5ori-07801.

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* This unit was built by P. W. Forsbergh, Jr. on the basis of information received from Professor P. W. Bridgman's laboratory at Harvard University.
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