whereas curve F is for quadratic variation[26a] (see de Boer, reference 11). It will be seen from Fig. 5 that the experimental points lie somewhere in between the various theoretical curves, all of which differ only slightly in the phenomenological basis for their computation.

It is concluded, therefore, (a) that the experimental results do not provide evidence for establishing whether the λ-transition of the solutions is of first or second order; (b) from the general agreement of the results with the theories of de Boer and Gorter, that the basic assumptions of non-superfluidity of pure liquid He^3 and of the Taconis solubility law receive welcome confirmation, and (c) that the general type of free-energy function for liquid helium II (pure He^4) which forms the basis of the computations shown in Fig. 5 is satisfactory for both types of transition, even down to the lowest λ-temperature measured (0.38°K).

As is well known the "condensation" temperature, T_λ, of a perfect Bose-Einstein gas is proportional to the number density of particles to the two-thirds power. The observed decrease in the λ-temperature of liquid He^4+He^3 solutions with decreasing He^4 concentration, as reported herewith, might be ascribed therefore to this decrease in the number density of Bose-Einstein particles. Although the conditions obtaining in a perfect gas cannot adequately represent those of liquid helium, it was considered to be of interest to calculate the expected variation of T_λ for a perfect He^3+He^4 gas mixture with concentration, x, of He^3, assuming the liquid mixture densities. The liquid mixture densities were calculated by assuming the law for perfect solutions using the known values of the molar volumes of pure liquid He^4 (27.6 cc) and pure liquid He^3 (37.5 cc) at the lowest temperatures. The result of this calculation is given by curve H of Fig. 4, T_λ at $x=0$ being normalized to 2.18°K. In view of the range of experimental error in measurement of T_λ (especially, as noted, that for the point at $x=42$ percent) it would appear that curve H represents the results as adequately as curves B and E which are the closest fit to the experimental results on the basis of the theory of de Boer and Gorter.[12] It is hoped to present later the detailed relationship between these various methods of calculation of T_λ.

Note added in proof.—O. G. Engel and O. K. Rice [Phys. Rev. **78**, 55 (1950)] have recently also proposed a thermodynamic model to allow calculation of T_λ as a function of x for high concentrations of He^3. In it, as in the models discussed above, the observed results can only be calculated after making *ad hoc* assumptions regarding the free energy of pure liquid He^4 in the normal state. A detailed discussion must, however, be postponed for a subsequent communication.

[26a] The quadratic temperature function is indicated by extrapolation of the entropy *versus* temperature curve below T_λ (see Daunt and Mendelssohn, Proc. Roy. Soc. **A185**, 237 (1946)) and is the same as that obtained for the roton spectrum postulated by Landau (J. Phys. U.S.S.R. **11**, 91 (1947)).

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On the Azimuthal Asymmetry of Cosmic-Ray Intensity above the Atmosphere at the Geomagnetic Equator*

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By means of Geiger-Mueller tube telescopes in an Aerobee sounding rocket fired to high altitude at the geomagnetic equator, information on the azimuthal asymmetry of the cosmic-ray intensity above the atmosphere has been obtained. These results, in conjunction with previously reported vertical intensities and specific ionizations at $\lambda=0°$ and $\lambda=41°N$, are consistent with the hypothesis that most of the primaries are positively charged protons with differential number spectrum of the form $dN=KE^{-1.9}dE$ in the energy region 5 to 23 Bev.

1. INTRODUCTION

A PREVIOUS paper[1] reports cosmic-ray intensities above the atmosphere at the geomagnetic equator as obtained by means of Aerobee sounding rocket A10 fired from the USS Norton Sound on March 17, 1949. From the same set of data, information on the azimuthal asymmetry[2] has been derived by a detailed analysis of the variation of the counting rate of telescopes AOB, XOY (axes at 45° to the rocket axis) as the rocket rotated about its longitudinal axis. This information is presented herein.

2. EXPERIMENTAL RESULTS

It is essential in measurements of this type to know the angular motion of a system of axes fixed in the rocket, and hence of the telescope axes, during the flight of the rocket above the appreciable atmosphere. Two devices were used in the A10 flight for this purpose. The first was a system of sixteen photoelectric cells, whose apertures were systematically arranged to cover

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[1] J. A. Van Allen and A. V. Gangnes, Phys. Rev. **78**, 50 (1950).

[2] A preliminary and partially incorrect report was given at the Echo Lake Conference (June, 1949). A corrected manuscript was subsequently submitted for inclusion in the report of the conference.

various angles of view. By means of this system, a more-or-less continuous record of the angle between the longitudinal axis of the rocket and the "solar vector" (sun's rays) was obtained. The second device was a total-field magnetometer[3] equipped with auxiliary coils through which known calibrating currents were passed periodically. Analysis of the magnetometer data provided a record of the angle between the longitudinal axis of the rocket and the local terrestrial magnetic field vector.

In general, two widely different angular positions of the rocket axis (on the two intersections of two cones) simultaneously satisfy the photo-cell and the magnetometer data at any one instant. An unambiguous choice is made possible by following the progression of positions from launching.

The results of this analysis are shown in Fig. 1, in which are plotted the zenith angle and azimuth of the longitudinal axis of the rocket. Accuracy of the plot is estimated at $\pm 3°$ in zenith angle and $\pm 5°$ in azimuth over most of the range shown.

Throughout the flight era considered, the period of roll of the rocket about its longitudinal axis was accurately constant at 3.53 seconds, as determined by both photoelectric cells and magnetometer.

Fiducial marks were placed on the long strip of telemetering record at the successive times at which a particular photo-cell was centered on the solar vector. The intervals between such marks were divided into 18 equal segments, corresponding to 20° intervals of roll angle. Each telescope coincidence (unassociated with a guard count) *AOB*, *XOY* was then recorded in the appropriate interval of roll angle so as to build up the histogram shown in Fig. 2. (Counts *XOY* were shifted 180°, then added to counts *AOB* to yield the composite histogram.) An equation of the form $y = a_0 + R\cos(\phi+\delta)$ was then fitted to the histogram by least squares technique. The result is shown as a smooth curve in Fig. 2. The values of the parameters, with their statistical probable errors are as follows: $a_0 = 18.7 \pm 0.7$, $R = 3.6 \pm 1.0$, $\delta = 87° \pm 15°$. The maximum of the fitted curve occurs at a geomagnetic azimuth of $268° \pm 15°$ (i.e., approximately west). The ratio $2R/a_0 = 0.39 \pm 0.11$. For a telescope of effective azimuthal acceptance angle 2α, the observed asymmetry must be increased by a factor $\alpha/\sin\alpha$. The corrected value $2R/a_0$ is

$$0.41 \pm 0.11.$$

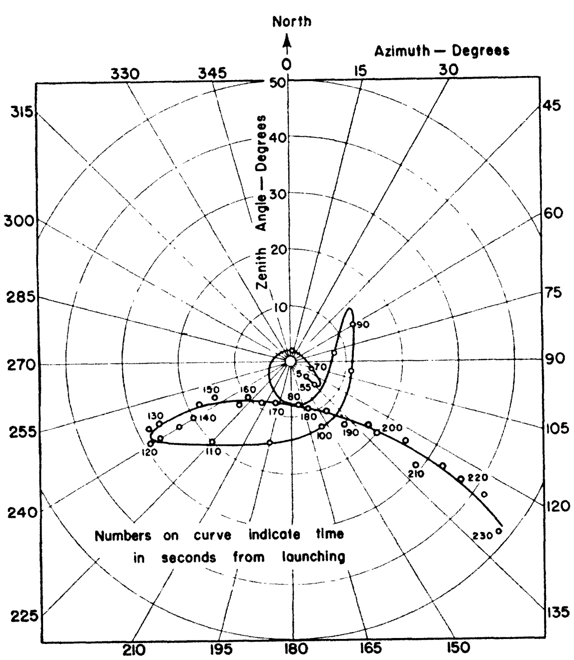

FIG. 1. Trace of forward end of rocket axis on a unit hemisphere, whose axis is vertical.

In order to confirm the significance of the parameters in the above fitted curve, histograms were prepared for *AOB* and *XOY* separately and also for a shorter interval of flight time during which the rocket axis was more nearly vertical. The sense and phase of the asymmetry agreed in all cases with those of the total histogram and the magnitudes of the parameters likewise agreed within their statistical significance. The multiple particle events were found to exhibit *no* significant correlation with azimuth of the telescopes.

Unfortunately, not enough data were obtained during transit through the Pfotzer maximum to either confirm or contradict the asymmetry measurements of Johnson and Barry.[4]

3. INTERPRETATION

The above value $2R/a_0$ cannot be simply interpreted as a conventional east-west asymmetry because of the fact that the rocket axis was not vertical. In order to arrive at an understanding of the result, we have proceeded as follows:

(a) The data of Fig. 1 were plotted on a graduated sphere.
(b) Corresponding to points on this plot, circles were drawn on the sphere to represent the trace of the axes of the *AOB*, *XOY* telescopes as the rocket rotated about its longitudinal axis.
(c) The sphere was then marked at various zenith and azimuth coordinates with the geomagnetic cut-off energies[5,6] (for protons).
(d) Finally, from the composite of telescope axis traces, the average cut-off energies corresponding to the azimuths of maximum and minimum counting rate were estimated to be 11 Bev and 23 Bev, respectively.

Thus the apparent directional intensity of particles of energy greater than 11 Bev is found to be 0.048 ± 0.003/sec./cm^2/steradian; and that of particles of energy greater than 23 Bev, to be 0.031 ± 0.003/sec./cm^2/steradian.

[3] The magnetometer was supplied by the Naval Ordnance Laboratory of White Oak, Maryland. We are particularly indebted to Mr. W. A. Bowen of NOL and Dr. S. F. Singer of this Laboratory for this phase of the work.

[4] T. H. Johnson and J. G. Barry, Phys. Rev. **55**, 503 (1939); **56**, 219 (1939).
[5] M. S. Vallarta, Phys. Rev. **74**, 1837 (1948).
[6] R. A. Alpher (private communication).

In the previous paper[1] it was found that a zenith angle dependence of intensity, averaged over all azimuths, of

$$0.028(1+0.6\sin\theta) \qquad (1)$$

is consistent with the intensity measurements by the various telescopes in this flight at $\lambda=0°$. On the other hand the geomagnetic theory predicts, for a reasonable power law spectrum of protons, a slight fall-off of intensity with increase of zenith angle.

Thus, it appears that Eq. (1) provides evidence for the increasing importance of atmospheric albedo at increasing zenith angles. This effect is no doubt present to an even greater extent in balloon measuremnts of the total intensity within the atmosphere.

If one temporarily ignores this evidence and the untenable result that the intensity of 0.031 for particles

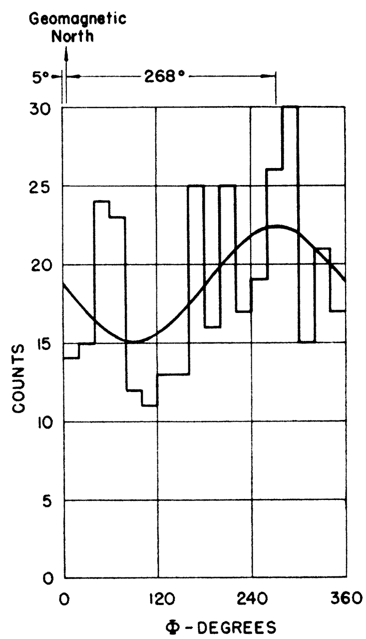

FIG. 2. Composite histogram of counts (unassociated with guard counts) from telescopes AOB and XOY in 20° segments of azimuth from an arbitrary zero, taken over 137.21 seconds of flight time during the interval 61.17 to 201.92 seconds after lauching. The smooth curve is a least squares fit to the histogram of the form $y=a_0+R\cos(\phi+\delta)$.

of energy greater than 23 Bev is higher than the (vertical) intensity of 0.028 for particles of energy greater than 14 Bev, and sets

$$(0.048/0.031)=(23/11)^{\gamma-1},$$

then $\gamma=1.6$. This is the exponent of a supposed power law differential spectrum of primaries—a value similar to, but less than, the value 1.9 deduced in the previous paper from comparison of vertical intensities at $\lambda=0°$ and $\lambda=41°$N.

In view of the conclusions of reference 1 and the foregoing discussion, it is likely that both the "11-Bev" and "23-Bev" intensities contain a significant contribution of secondaries. An equal subtraction of reasonable magnitude from each of these figures increases the calculated value of γ, and tends to bring it into agreement with the value deduced from the latitude effect.

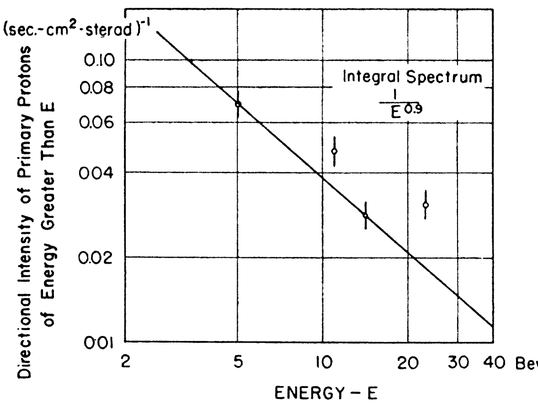

FIG. 3. A provisional integral spectrum, in absolute units, of the directional intensity of primary protons of energy greater than E as a function of E.

4. CONCLUSIONS

Thus, it appears that the measured asymmetry above the atmosphere at the geomagnetic equator can be regarded as consistent with the already widely held belief that most of the cosmic-ray primaries are ordinary positively charged protons. In this connection there may be mentioned a previous experiment[7] at $\lambda=41°$N and a subsequent one[8] at $\lambda=0°$, which have shown by direct measurement that the high energy charged particles above the atmosphere are predominantly *singly charged.*

A provisional *integral* number spectrum is plotted in Fig. 3, giving absolute intensities of primary protons of energy greater than E as a function of E. The curve of the form of $E^{-0.9}$ has been passed through the two "latitude" points; the deviation of the "asymmetry" points is evident.

This expedition was made possible by the continuing support of the U. S. Navy Bureau of Ordnance and by the cooperation of many other branches of the Naval organization: in particular, the Naval Unit of the White Sands Proving Ground, the USS Norton Sound, the USS Agerholm, and the USS Richard B. Anderson.

We are indebted to Professor M. S. Vallarta and to Dr. S. F. Singer for discussion of the results. Mr. L. W. Fraser of this Laboratory and Mr. R. F. Ohlemacher of the New Mexico College of Agriculture and Mechanic Arts have contributed essentially in accomplishing this experiment.

[7] S. F. Singer, Phys. Rev. **76**, 701 (1949).
[8] S. F. Singer, Echo Lake Conference (June, 1949).