that the assumptions made will not be valid for a star which emits cosmic-ray particles, all carrying the same charge, at this rate. The range of applicability is limited, in the case of a typical star, to rates of emission which are less than this indicated upper limit by a factor of at least 10^{-3}. This still might reasonably be termed an upper limit, and will result in producing a potential on the star of the order of one volt.

The calculations indicate, then, that the cosmic-ray particles will produce very small potentials on the stars. Since these potentials represent the only electric fields set up by the rays, one is led to the general conclusion that, as far as regards the electric fields that would be produced, theoretically it is possible for cosmic rays to originate, and to exist in interstellar space, as charged particles predominantly of one sign.

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The East-West Asymmetry of the Cosmic Radiation at High Latitudes

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The sea-level east-west asymmetry of unabsorbed cosmic radiation and of that radiation penetrating two thicknesses of lead, 20° from the vertical, has been measured at geomagnetic latitude 54°N, well above the knee of the latitude effect. Two methods were used to calculate the asymmetry from the data. The results are given in Table I.

The Stoermer-Lemaître-Vallarta theory of the trajectories of primary cosmic rays in the earth's magnetic field explains the east-west asymmetry near the equator, but this effect should vanish above the knee of the latitude effect where field sensitive rays are not able to penetrate to sea level. Nevertheless, a small sea-level asymmetry has been found[1] at geomagnetic latitudes up to 51°N, approximately 10° higher than the recognized position of the knee. Moreover, experiments 6288 ft. above sea level by Johnson[2] indicated that an asymmetry exists as far north as geomagnetic latitude 56°. While these latter experiments lacked precision, some slight influence of the primary asymmetry might still have been present in the former; therefore, it seemed important to investigate the asymmetry again as accurately as possible at higher latitudes in order to make sure of the existence of such an asymmetry and to ascertain if any variation of this high latitude asymmetry with latitude is detectable. The measurements to be described were made in Troy, New York, geomagnetic latitude 54°N. In order to obtain the greatest precision in a limited time, all the measurements were made at one zenith angle, 20°. However, various thicknesses of lead absorber were used to remove the softer radiation.

A double-coincidence cosmic-ray counter was used to measure the asymmetry. This apparatus was placed in a wooden structure of uniform wall

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[1] T. H. Johnson, Phys. Rev. **48**, 287 (1935); T. H. Johnson and E. C. Stevenson, *ibid.* **44**, 125 (1933); E. C. Stevenson, *ibid.* **44**, 855 (1933); J. C. Stearns and R. D. Bennett, *ibid.* **43**, 1038 (1933); A. Ehmert, Physik. Zeits. **35**, 20 (1934); J. C. Stearns and D. K. Froman, Phys. Rev. **46**, 535 (1934).

[2] T. H. Johnson, Phys. Rev. **43**, 381A (1933) and J. Frank. Inst. **214**, 665 (1932).

thickness located upon a hill, from which there were no obstructions in the paths of the rays to be measured. Figure 1 shows the arrangement of the coincidence units and lead absorber. The two trays of G-M tubes and the lead were supported by a sturdy wooden frame free to rotate around a vertical axis. The frame could be tilted at any angle away from the vertical. The sensitive solid angle determined by the apparatus extended almost 20° in either direction beyond the zenith-angle setting—as is evident from Fig. 1—and 37° in either direction of the azimuthal setting.

Two spirit levels mounted on the frame, one perpendicular, the other parallel to the axes of the G-M tubes, enabled the zenith angle to be reproduced after each reversal of azimuth to better than ±0.1°. Azimuthal settings were made perpendicular to a magnetic meridian which was determined by sighting away from Polaris at an angle equal to the magnetic declination.

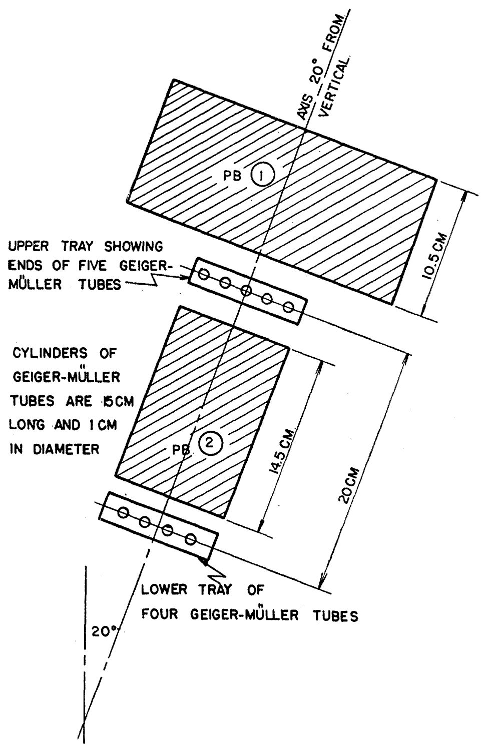

FIG. 1. Arrangement of counter tubes and of lead for measurement of the asymmetry at 20°.

Figure 2 shows a circuit diagram of the apparatus. Each unit of the double-coincidence counter was a tray of G-M tubes connected in parallel; the upper tray contained five tubes side by side in a plane, the lower tray contained four tubes. All these tubes were the same, having cathode cylinders of seamless copper tubing, 15.1 cm long, 1.0 cm inside diameter, and tungsten wire anodes 3 mils in diameter. They were operated in an atmosphere of 94 percent argon and 6 percent oxygen at 8 cm of Hg pressure with −760 volts on their cathodes. This high voltage was obtained from a Street-Johnson[3] regulated high voltage circuit. *B* and *C* voltages were taken from a regulated voltage supply having a circuit very similar to that of an RCA TMV-118-B regulated power unit. Finally, in order to avoid spurious counting, the whole apparatus including G-M tubes, recording circuit, power supplies, and cables were shielded electrostatically.

Frequent tests showed that the only counts recorded originated from G-M counter discharges. With the two coincidence units separated horizontally by 85 cm, the number of accidental coincidences was found to be 3.80±0.22 counts per hour; but, since the asymmetry is a relative measurement, any correction for accidentals, showers, or inefficiency is unimportant, because these effects are constant with azimuth.

The mechanical recorder, operated by the plate current of a type 89 tube, consisted of a small electromagnet working the escapement wheel of an Ingersoll watch. During part of the investigation, two of these recorders were connected in series and found to give the same number of counts. The counting periods were timed to about one part in ten thousand by two electric clocks.

The apparatus was run on a 24-hour schedule almost continuously from December 1, 1939 until August 2, 1940. During this time, runs were made with 25 cm of lead absorber (blocks No. 1 and No. 2 of Fig. 1 in place), with 14.5 cm of lead (block No. 2 in place), and with no absorber (blocks No. 1 and No. 2 removed). According to the Bethe-Bloch theory of ionization,[4] 25 cm of lead is the range of a mesotron of 3.5×10^8 ev and

[3] J. Street and T. H. Johnson, J. Frank. Inst. **214**, 155 (1932).
[4] See S. H. Neddermeyer and C. D. Anderson, Rev. Mod. Phys. **11**, 191 (1939).

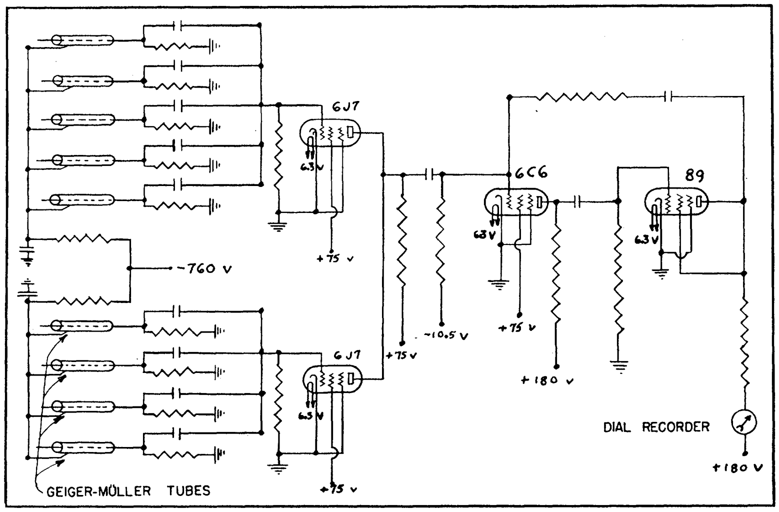

FIG. 2. Double-coincidence counter circuit.

14.5 cm of lead is the range of a 2.2×10^8-ev mesotron.

Data collected during most of April, 1940, exhibit a barometer effect of the expected magnitude. These data were taken by turning the apparatus towards the west for 12 hours, towards the east for 12 hours, then back to the west again, etc. Upon comparing the number of times a barometer correction would increase the value of the asymmetry to the number of times such a correction would decrease the asymmetry, it was found that a barometer correction of this particular data would not have appreciably influenced the average value of the asymmetry. This justifies neglecting the correction to the data for barometric fluctuations, especially, since about $\frac{2}{3}$ of the data for the no-lead value and $\frac{2}{3}$ for the 14.5-cm-of-lead value have been obtained from a series of six-hour runs made in the order of east-west-west-east-east-west, etc.

In order to remove any possible influence of diurnal cosmic-ray intensity variations, the times of day during which intensities from the east and west were recorded were interchanged once a week.

Two methods were used to obtain the asymmetry from the data. The result of the first method is denoted by α_{20° and was obtained by the relation

$$\alpha_{20^\circ}=2(\bar{j}_w-\bar{j}_e)/(\bar{j}_w+\bar{j}_e), \qquad (1)$$

where $\bar{j}_w$ and $\bar{j}_e$ are, respectively, the average cosmic-ray intensities from west and east with the apparatus tilted 20° from the vertical. The probable error of α_{20° was obtained from the probable errors of $\bar{j}_w$ and $\bar{j}_e$; and the probable errors of the latter were taken as $\pm 0.6745(\bar{j}/\sqrt{N})$, where N is the total number of counts used to determine $\bar{j}$. In the second method the intensities $\bar{j}_w$ and $\bar{j}_e$ used in Eq. (1) were replaced by j_w and j_e to obtain an asymmetry for each pair of east-west runs. The arithmetic mean of these asymmetries was calculated by weighting each asymmetry according to the length of time used in the determination of its j_w and j_e, and this mean is denoted by $\bar{\alpha}_{20^\circ}$. The probable error of $\bar{\alpha}_{20^\circ}$ is taken to be

$$\pm 0.6745[(n-1)\sum_n f_i]^{-\frac{1}{2}}[\sum_n f_i d_i^2]^{\frac{1}{2}},$$

where f_i is the weight of the asymmetry for the ith pair of runs and d_i is its deviation from the mean.

Table I shows the values of the asymmetry for various thicknesses of lead absorber together with their probable errors. It may be noticed that the values for α_{20°, $\bar{\alpha}_{20^\circ}$, and their probable errors are practically identical except for 25.0 cm of lead. In this case the discrepancies can be accounted for by an uncertainty in the operation of the recorder, leading to larger fluctuations but, presumably, to no systematic errors.

The value for the asymmetry of the total unabsorbed radiation is in agreement with asymmetry observations made 20° from the

TABLE I. *Data on asymmetry.* E_{min} *is the minimum energy required to penetrate the lead shielding.*

E_{MIN} (EV)	CM PB	ASYMMETRY $\alpha_{20°}$	$\bar{\alpha}_{20°}$	INTENSITY AT 20° FROM VERTICAL (COUNTS/HOUR) 20°W	20°E	AVE.
—	0.0	+0.0009 ±0.0022	+0.0010 ±0.0022	249.03 ±0.40	248.81 ±0.40	248.92 ±0.28
2.2×10^8	14.5	+0.0075 ±0.0026	+0.0073 ±0.0027	174.02 ±0.32	172.72 ±0.31	173.37 ±0.22
3.5×10^8	25.0	+0.0062 ±0.0032	+0.0056 ±0.0048	164.40 ±0.37	163.38 ±0.37	163.89 ±0.26

vertical by Johnson[5] at geomagnetic latitude 51°N, although he obtained values at neighboring angles more nearly in accord with those found in the present work with the lead shields. Comparison of these results indicates no marked difference in the asymmetries in latitudes 51°N and 54°N.

The theory of the asymmetry resulting from deflections of charged particles in the atmosphere has been developed by Johnson,[6] and in the light of his theory it is interesting to compare the effect of lead absorbers upon the asymmetry with a corresponding effect of lead shields upon the excess in the number of positive over negative mesotrons found in cloud-chamber photographs at sea level. Although Hughes[7] and Jones[8] have found no significant difference in the ratio of positives to negatives when a 10-cm lead plate was inserted between their controlling counters, Leprince-Ringuet and Crussard[9] found the positive excess was considerably amplified when 14 cm of lead were used. Their results may thus have some relation to the difference found in the present work between the asymmetries with and without shields. For example both results would be explained if the lead absorbs negative rays selectively and allows a larger fraction of positives in the low energy range to pass through. In attempting to explain the apparent effect of lead shields upon the asymmetry it must be noted that the present results contain rather large probable errors and there is a distinct possibility that the effect may be the result of statistical fluctuations.

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[5] T. H. Johnson, Phys. Rev. **48**, 287 (1935).
[6] T. H. Johnson, Phys. Rev. **59**, 11 (1941), following paper.
[7] D. Hughes, Phys. Rev. **57**, 592 (1940).
[8] H. Jones, Rev. Mod. Phys. **11**, 235 (1939).
[9] L. Leprince-Ringuet and J. Crussard, J. de phys. et rad. **8**, 207 (1937).