THE

PHYSICAL REVIEW

A Journal of Experimental and Theoretical Physics Established by E. L. Nichols in 1893

VOL. 56, NO. 3 — AUGUST 1, 1939 — SECOND SERIES

The East-West Symmetry of the Cosmic Radiation at Very High Elevations Near the Equator and Evidence that Protons Constitute the Primary Particles of the Hard Component

THOMAS H. JOHNSON AND J. GRIFFITHS BARRY, *Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania and The Carnegie Institution of Washington, Washington, D. C.*

(Received May 29, 1939)

The east-west symmetry of the soft component of the cosmic radiation has been investigated near the equator by sending triple coincidence counters into the stratosphere with free balloons. The data were transmitted to a ground station by radio signals. Direct comparisons between eastern and western intensities were made on flights in which the orientation of the instrument was determined by means of a photo-cell actuated by light from the sun. On other flights we have studied the fluctuations which would be introduced into the counting rates by the rotation of the balloon if the radiation were asymmetric. The results show that the asymmetry is less than about seven percent, a value far below what would have been expected if all of the primary radiation were positive. Analysis shows that less than about ten percent of the intensity at a depth of one meter of water is attributable to unbalanced positives. Contrasting this result with that found from the asymmetry at sea level that the mesotrons of the hard component are produced entirely by positive primaries, it becomes necessary to conclude that the mesotrons are produced in the upper atmosphere, not by the primary electrons of the soft component, but by an independent primary component consisting probably of protons or some other more massive positive ion. Reasons based upon the electrical properties of space are advanced to show that it is reasonable to expect to find protons of high energy in the primary cosmic radiation.

INTRODUCTION

It is generally recognized that the cosmic radiation in the atmosphere consists of two components, the soft component, constituting most of the intensity at high elevations, and the hard component which predominates at sea level. The soft component is fully accounted for[1] by the assumption that its primaries are electrons of the energies required to pass through the earth's magnetic field but the interpretation of the hard component is more difficult. Its particles are mesotrons of intermediate mass and there are at least three reasons for thinking that these particles are created in the atmosphere by some other type of primary particle. In the first place the energies of the mesotrons at sea level are incompatible with the latitude effect if the mesotrons are themselves the primary particles. If one computes the energy distribution of these rays at the top of the atmosphere by adding to the energies of the rays found at sea level that which is known to be lost in passing through the atmosphere, about half of the primary rays would have an energy less than 15 Bev and would not be able to reach the earth at the equator. The observed latitude effect on the other hand is less than ten percent.[2] Secondly, mesotrons are

[1] R. Serber, Phys. Rev. **54**, 317 (1938); H. Snyder, Phys. Rev. **53**, 960 (1938); J. F. Carlson and J. R. Oppenheimer, Phys. Rev. **51**, 220 (1937).

[2] This argument was first advanced in a slightly different form by Bowen, Millikan and Neher, Phys. Rev. **53**, 217 (1938). See also L. W. Nordheim, Phys. Rev. **53**, 694 (1938).

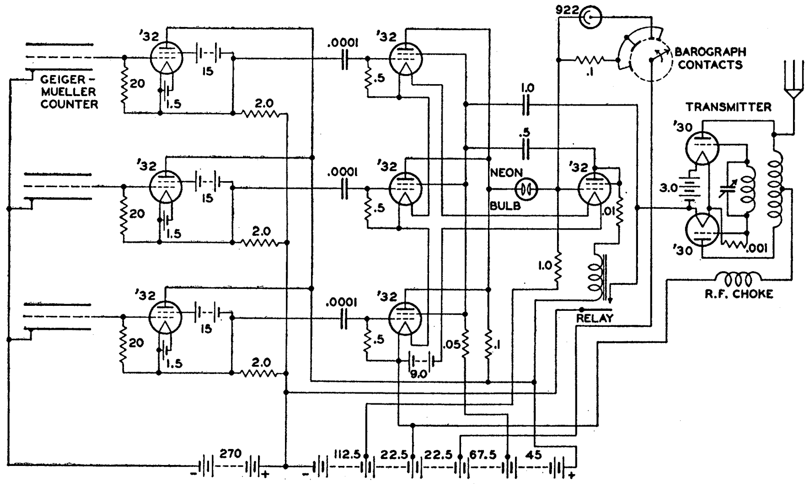

FIG. 1. Circuit used in the balloon apparatus. Capacities are given in microfarads, resistances in megohms, vacuum tubes by RCA, and G. E. Vapor Lamp Company.

probably unstable and would not survive a long journey through space. The mean life found from the experiments[3] corresponds with a path through space of only 150 km in the case of particles of 10 Bev energy. Thirdly, the equality of the numbers of positives and negatives found in the cloud-chamber experiments[4] is incompatible with the east-west asymmetry unless the mesotrons are secondaries produced in the atmosphere. There is at the most but a slight preponderance of positives at sea level whereas the asymmetry indicates that practically all of the primary particles of the hard component are positive.[5] There can thus be little doubt that the mesotrons are secondaries produced in the atmosphere and the problem arises to determine what type of particles compose their primary radiation.

If the electrons of the soft component were also the primaries of the hard component, it would be necessary to suppose that these are largely positrons in order to explain the sea-level asymmetry. In that event the soft component should also show a considerable asymmetry. On the other hand, if the mesotrons are produced by some other type of primary particle, the soft component primaries might be equally positive and negative and show no east-west asymmetry. The first attack on this question was made by one of us[6] in 1934 by measuring the east-west asymmetry of small showers produced in two centimeters of lead at an atmospheric depth of six meters. In those experiments it was shown that the asymmetry was less than a percent or two, compared with a fifteen-percent asymmetry of the penetrating component at the same station, although it was known from the variation of the same type of shower with latitude that the primary rays involved were field sensitive. However, in view of possible uncertainties attending those experiments in regard to which component was chiefly involved in the effects measured and in regard to the directional selectivity of the instrument, the matter obviously deserved further study.

EXPERIMENTS

Following a period of development of the radio balloon technique[7] we have at last succeeded in measuring the asymmetry of the

[3] For a discussion of these experiments and their interpretation see H. Euler and W. Heisenberg, *Ergebn. d. Exakt. Naturwiss.*, 1938. See also T. H. Johnson and M. A. Pomerantz, Phys. Rev. **55**, 104 (1939).

[4] P. M. S. Blackett, Proc. Roy. Soc. **A159**, 1 (1937).

[5] A resumé of these experiments and their interpretation was given by T. H. Johnson, Rev. Mod. Phys. **10**, 193 (1938).

[6] T. H. Johnson, Phys. Rev. **47**, 318 (1935).

[7] T. H. Johnson, J. Frank. Inst. **223**, 339 (1937); Phys. Rev. **54**, 151 (1938); Curtiss, Astin, Stockmann, Brown and Korff, Phys. Rev. **53**, 23 (1938).

cosmic radiation near the equator at high elevations where the intensity is largely that of the soft component.[8] The flights were sent up from the Barro Colorado Island Laboratory of the Institute for Research in Tropical America, located in the Panama Canal Zone 20° north of the geomagnetic equator. In that latitude the band of energies contributing to the asymmetry is nearly as great as at the equator itself. Out of a total of ten flights, four resulted in complete records from which direct comparisons could be made of the intensities in the eastern and western directions at depths of less than one and one-half meters of water. Two of the remaining flights yielded exceptionally good cosmic-ray data but the orientation record was lacking. These data have been useful nevertheless for a study of the possible fluctuations which would be introduced by the rotation of the balloon if the radiation were asymmetric.

On all of these flights the cosmic rays were detected by a train of three coincidence counters with the principal axis of the train inclined 60° from the zenith. Each counter was four inches long and one-half inch in diameter and the extreme counters were separated one and one-half inches from center to center. Half or more of the counter area was sensitive for a range of zenith angles of about 20° and a range of azimuths of about 90°. The counters were filled to a pressure of 15 cm Hg with a mixture of ten percent hydrogen and ninety percent neon, and their operating potential was about 500 volts. A vacuum tube circuit (Fig. 1) already described by one of us[9] was used for stabilizing the discharges, and with this arrangement the recovery time was so short that no appreciable inefficiency was experienced at the counting rates attained in the stratosphere. With the triple coincidences the accidental rate was also low and amounted, according to tests made at the start of each flight, to less than two or three percent of the counting rates observed in the stratosphere. The coincidence selection stage employed the usual Rossi parallel plate connection with neon tube coupling to the output stage. The pulses resulting from coincidences were prolonged to produce radio signals of sufficient duration for satisfactory recording by means of two capacity coupled feedbacks to the screen grid circuit of the selection stage from the plate of the output tube and from the relay contact, respectively. The resulting pulses were about one-quarter of a second long, a time which depended entirely upon the circuit and was quite independent of the amplitude of the input pulse as long as the latter was sufficient to produce the initial flash in the neon tube. The barograph has also been described elsewhere.[10] In addition to the usual contacts for indicating the barometric pressure and the temperature the barographs used for this series of flights were also provided with a third contact for indicating the orientation. This contact was fixed in position but was connected to the output tube through a photo-cell upon which the rays of the early morning sun could fall when the counter train was pointing eastwards. The corresponding signal was transmitted only during the eastern half of the rotation cycle. The radio transmitter consisted of two RCA 30 tubes in push pull with capacity tuning in the grid circuit, and was operated from a 135-volt plate battery. All B-voltages were supplied by Burgess V30FL batteries and the additional high voltage for the counters by National Carbon Company X-180 batteries. The entire apparatus with batteries and rigging weighed about nine pounds.

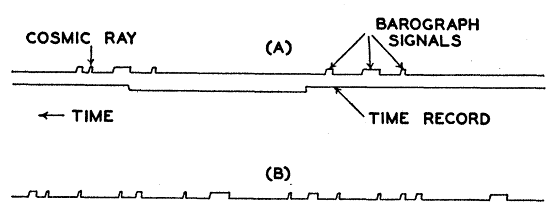

FIG. 2. Two portions of a flight record covering about ten seconds; (*A*) near sea level and (*B*) in the stratosphere.

The recording apparatus located at the ground station consisted of a National 1–10 super-regenerative receiver with one stage of radio-frequency amplification. The output from the power stage was rectified with a diode and then

[8] A brief preliminary report of these experiments has already been published. T. H. Johnson and J. G. Barry, Phys. Rev. **55**, 503 (1939).

[9] T. H. Johnson, Rev. Sci. Inst. **9**, 218 (1938).

[10] T. H. Johnson and S. A. Korff, Rev. Sci. Inst. **10**, 82 (1938).

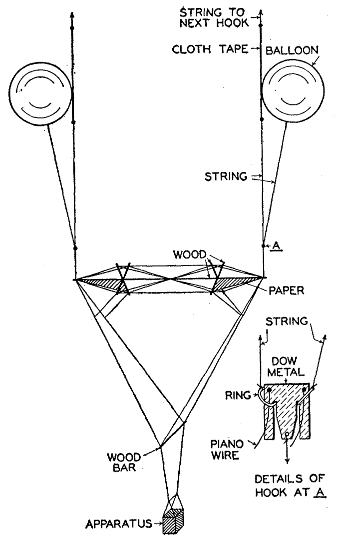

FIG. 3. Suspension used for attaching apparatus to the balloons for the asymmetry experiments. The ten-foot spacing bar was rotated by paper vanes attached at each end. The lower suspension allowed the apparatus to hang vertically. The hooks shown in the insert permitted the fragments of the exploded balloons to fall away. The radio transmitter, not shown, hung above the apparatus.

passed through two stages of direct coupled amplification to a magnetic recording pen which traced a line on a paper tape. Two portions of the record of one of the flights are shown in Fig. 2.

For the asymmetry studies the apparatus was suspended by two strings of balloons separated by a ten-foot spacing rod, Fig. 3. Paper vanes were attached to the ends of this rod so that as the balloons ascended the entire rigging rotated slowly in azimuth. The lower suspension was designed to keep the instrument vertical in spite of unequal forces from the two strings of balloons, after one of the balloons had burst. Each balloon was attached by means of a special release hook, the details of which are shown in the insert, so that after the bursting the remnants of the balloon fabric fell away from the rigging, eliminating the uncertain factor in the final weight of the equipment. It was thus possible to calculate the inflations so that the flights would come into static equilibrium after the bursting of the first balloon and several flights were realized in which the balloons remained at one level for several hours. On most of these flights six balloons have been used, inflated so that with five balloons the instrument would just float. The average ceiling pressure was 30 mm Hg and the initial rising velocity was about 500 ft. per minute. At this speed the rotation varied irregularly from one-half to three revolutions per minute, but after the bursting of the first balloon the rotational speed decreased to about one revolution in five minutes. Most of the data were obtained with the lower rotational speeds.

Unfortunately none of the four flights for which the record was complete stayed at the ceiling for a long period of time and it has been necessary to combine all of the data recorded on these flights at elevations above a depth of one and one-half meters of water. The data are not sufficient to show how the asymmetry varies with elevation, but they are consistent in regard to the average asymmetry for the higher levels. A resumé of these data is given in Table I. The average asymmetry calculated from the four flights is

$$\alpha = 2(j_w - j_e)/(j_w + j_e) = 0.072. \quad (1)$$

No very reliable estimate of the probable error of the final average can be made other than to note the variations from one flight to another.

On two other flights the orientation signal failed to operate satisfactorily although the cosmic-ray data were remarkably good. One of these flights remained at a pressure of 35 mm for seven hours with a continuous counting rate of about 120 counts per minute; the other remained for four hours at a pressure of 49 mm. Subsequent experience under similar circumstances showed that the rotation of the balloon

TABLE I. *Resumé of data.*

Flight No.	Minimum Depth (Meters of Water)	East Counts	East Time (min.)	East Rate j_e	West Counts	West Time (min.)	West Rate j_w	α
110	0.40	1100	28.3	38.9	1523	35.4	43.0	0.10
112	0.45	277	10.5	26.3	413	14.9	27.6	.048
113	0.60	464	18.5	25.1	680	24.6	27.6	.095
B	0.33	554	19.3	28.7	740	23.8	31.1	.080
Average weighted according to the total counts								0.072*

* The discrepancy between this value and that published in our preliminary account (reference 8) arises from the fact that in our earlier reductions we did not realize the existence of certain spurious counts which occurred on the western half of the rotation cycle during the time when the photo-cell signal would have been transmitted if the cell had been illuminated. During that brief period the dark current through the cell raised the potential of the output tube grid and made the circuit less selective against single and double discharges. Since the period when these pulses could be recorded was known it was a simple matter to make this correction.

during this level portion of the flight must have continued at the rate of about one revolution in four minutes. Hence if there were an asymmetry in the radiation the rotation should introduce a fluctuation into the counting rate when broken down into periods short compared with that of the rotation. The data for one hundred ten-second periods from each of three flights have been analyzed with the results contained in Table II. Two of these flights are those referred to above and the third was flight 110 for which the orientation data were also available. If the time for the transmission of a signal could be neglected and the fluctuations were of a purely statistical nature the sums of the squares of the deviations from the average should be equal to the total number of counts recorded. The actual fluctuations were somewhat less than would have been expected on this basis and a correction was required for the dead time following each pulse during which a second pulse would have failed to record. If the dead time be designated by τ and the true counting rate, which would have been recorded if τ were equal to zero, by $\bar{N}$, then the average number of counts recorded in unit time is obviously

$$\bar{M}=\bar{N}/(1+\bar{N}\tau). \quad (2)$$

Similarly if in a given interval of unit length the actual number of counts which would have been recorded with $\tau=0$ is N, then the probable number of counts actually recorded is

$$M=N/(1+N\tau). \quad (3)$$

Thus the squares of the deviations of the observed counts from the average of the observed counts may be written as

$$(M-\bar{M})^2=(N/(1+N\tau)-\bar{N}/(1+\bar{N}\tau))^2 \doteqdot (N-\bar{N})^2(1-4\bar{N}\tau). \quad (4)$$

Thus the mean square deviation averaged over a large number of intervals, n, is given by

$$(1/n)\sum_n(M-\bar{M})^2 \doteqdot \bar{N}(1-4\bar{N}\tau) \doteqdot \bar{M}(1-3\bar{M}\tau). \quad (5)$$

TABLE II. *Analysis of data.*

Flight No.	Depth (Meters of Water)	Average Counts per ten sec. Interval	Mean of the Squares of 100 Deviations	Mean Square Deviation Expected from Statistics
103	0.47	14.1	9.0	9.0
104	0.66	13.7	8.2	8.9
110	0.40	4.30	3.8	3.8

The last column of Table II contains the mean of the squares of the deviations to be expected statistically in the case where $\tau=0.0085$ of the interval, a value obtained from the measurement of the width of the pulses on the actual records.

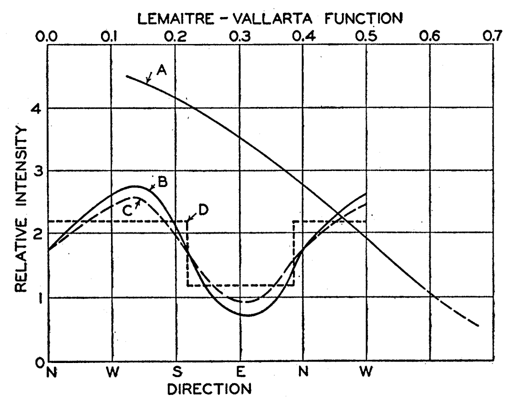

FIG. 4. Curves showing the asymmetry to be expected at 60° from the zenith and at a depth of $\frac{3}{4}$ meter of water calculated on the assumption that all of the soft component primary rays are positive. Curve A is the intensity at a depth of $1\frac{1}{2}$ meters of water in the vertical direction plotted as a function of the low energy limit expressed in terms of the Lemaitre-Vallarta function (scale above). Curve B is the azimuthal variation of the intensity at zenith angle 60° and depth $\frac{3}{4}$ meters, calculated from curve A (scale below). Curve C is that which would be measured, instead of B, with counters of the aperture used in the experiments. The square lines D represent the intensities as they are averaged by our method of taking observations.

It is seen that the expected values are in close agreement with those found from the data and there is thus no evidence of an azimuthal asymmetry from the fluctuations. If there had been a sinusoidal variation of intensity with azimuth of amplitude N_1 counts per interval this would have introduced a contribution to the mean square deviation of amount $\frac{1}{2}N_1^2$, and if we say that this contribution must have been less than ten percent of total mean square deviation in order not to have shown itself in the results we may conclude, in the case of flight 103 for example, that $N_1<1.3$ counts per interval or about ten percent of the average counting rate. The peak asymmetry is thus less than twenty percent, and the difference between the average counting rates on the eastern and western sides of the meridian, corresponding to the asymmetry given by (1), must be less than 13 percent. The fluctuational analysis is thus not in disagreement with the direct measurements.

Discussion

In order to perceive the significance of the observed asymmetry in relation to that which would be expected if all of the primaries were positive, the following calculation has been based upon the balloon flight data of Bowen, Millikan and Neher.[11] The vertical intensity at a depth of one and one-half meters of water has been determined from the experimental curves by the method of Gross[12] and plotted in curve A, Fig. 4 as a function of the low energy limit expressed in terms of the Lemaitre-Vallarta parameter. The same curve should also represent the intensity at the 60° inclined direction at a depth of $\frac{3}{4}$ meter if the intensity is a function of $h \sec \theta$. Making use of Lemaitre and Vallarta's determinations[13] of the azimuthal variation of the low energy limit for the latitude of 20°, curve A has been converted into curve B which should represent the azimuthal variation of intensity if all of the primaries were positive. Because of the finite aperture of our counter train which admits rays from a range of azimuths, the curve C represents what would have been observed if the observations had been precisely correlated with azimuthal angle. Since we have observed only the average counting rates on the eastern and western halves of the cycle our results are to be compared with the squared lines, D. Thus if all of the primaries were positive we would have expected to find an asymmetry of 0.60 instead of the value 0.072 as given by Eq. (1). Since this calculation is based upon the observed latitude effect the discrepancy cannot be attributed to neutral rays but is to be accounted for by the presence of negative primaries. If j^+ and j^- represent the intensities per unit range of the energy in this region of the primary spectrum, produced by positive and negative primaries, respectively, and if K designates the total intensity produced by neutral rays and rays whose energies exceed the upper limit of the asymmetric component, and if ΔE is the average range of energy contained in the asymmetric component, our results can be represented by the equation

$$2(j^+-j^-)\Delta E/(j^+\Delta E+j^-\Delta E+2K)=0.072, \quad (6)$$

whereas if j^- were zero in this region of the spectrum and a positive intensity $j^{+\prime}$ accounted for all of the variation of intensity with latitude, then we should have expected the asymmetry to be represented by

$$2j^{+\prime}\Delta E/(j^{+\prime}\Delta E+2K)=0.60 \quad (7)$$

where $j^{+\prime}$ must be chosen equal to $j^+ + j^-$ in order to preserve the same latitude effect in both instances. It thus follows by simple arithmetic that

$$j^-/(j^+ + j^-)=0.44$$

and
$$j^+/(j^+ + j^-)=0.56. \quad (8)$$

That part of the intensity produced by positives unbalanced by negatives is thus of the order of twelve percent of the total field sensitive intensity in this region of the spectrum. A part, if not all, of this intensity can be accounted for by the hard component and we must conclude that the soft component is very nearly balanced as regards the numbers of primary rays of the two signs of charge.*

In drawing the conclusion that an absence of an asymmetry is indicative of a balance between positives and negatives in the primary beam it is of course necessary to assume that there has been no appreciable alteration in the direction of the rays from that of their primaries after entry into the atmosphere. Inasmuch as no

[11] Bowen, Millikan and Neher, Phys. Rev. **53**, 855 (1938).
[12] See reference 4, page 197.
[13] See reference 4, page 218.

* The following argument that some of the asymmetry may be attributable to the soft component was pointed out in conversation by L. W. Nordheim. Since at a depth of one meter the soft component has multiplied to about thirty times the number of primary rays and if the hard component has not undergone an appreciable multiplication then the number of primary hard component rays, equal to ten percent of the total radiation at a depth of one meter, is $0.1\times 30=3$ times the number of primary soft rays. But the total energy, and therefore the total number of rays in the hard component, cannot be more than about ten percent of the total radiation. Therefore it is necessary to assume, either that the asymmetry is less than is indicated by the figures in Eq. (1), or that the hard component has undergone a multiplication of the order of thirty-fold at a depth of one meter, or that part of the asymmetry may be attributed to the soft component.

heavy matter lay above the counters no appreciable scattering could be readily accounted for.† The possibility of a spread of direction due to magnetic deflection of the secondary electrons of lower energies is discussed in the following paper[14] where it is shown that this effect cannot account for an average deflection of more than about five degrees. Furthermore the correction for this effect would be of a second order, for the rays produced by primaries from nearer the horizon would tend to increase the asymmetry while those from nearer the vertical would tend to diminish it. At the elevation of our measurements the variation of intensity with zenith angle is not rapid and the two effects would tend to balance each other. Thus there seems to be no escape from the conclusion that the soft component is composed of very nearly equal numbers of positives and negatives.

Contrasting this property of the soft component with the fact revealed by sea-level asymmetry measurements that the hard component is produced by primaries which are nearly all positive, it seems impossible to attribute the hard component to the soft component electrons as primaries, and it becomes necessary to suppose that some other type of primary particle produces the mesotrons.[15] Since the primaries of the hard component cannot be electrons, and, for the reasons cited in the introduction, they cannot be mesotrons, the next possibility in order is that they are protons, a suggestion which has been frequently made as an explanation of the asymmetry.[16] Although no protons which could be primaries are found in the cosmic radiation at sea level,[17] their absence may well be attributed to a nuclear absorption in which the mesotron production may be an important process. The cross section for nuclear collisions should be at least of the order of $\pi r_0^2 = 2.5\times10^{-25}$ for which the absorption coefficient is 1.0 per meter of water, and only one ray in 25,000 would reach sea level. Absorption coefficients of this order have already been found for large bursts, for slow neutrons, and for nuclear explosions. At least the latter two phenomena might be interpreted as resulting from primary protons.

It may also be pointed out that the well-known difficulty in explaining the 40° position of the knee of the latitude effect is removed by the assumption that the primary rays of the hard component are protons. The critical energy with which protons are admitted at 40° latitude is 6.4 Bev and the maximum kinetic energy that a proton of this energy could impart to a mesotron of one-tenth the proton mass in a head-on collision is 3.1 Bev. This figure is in more satisfactory agreement with the energy lost by ionization in passing through the atmosphere than the value 7.5 Bev obtained from the primary electron hypothesis, so that the latitude of the knee may be that where the mesotrons of maximum energy are just able to penetrate the atmosphere.

Reasons for expecting to find protons in the primary cosmic radiation, regardless of the nature of the initial cosmic-ray particle or of the process by which it acquired its initial energy, have already been advanced by one of us.[18] At the source we assume the existence of matter in the familiar static form in which protons are positive and electrons are negative, and we may assume that either (a) electrons or (b) protons acquire an initial energy of the order of cosmic-ray energies. In case (a) the electron current charges the source to a high positive potential and in the electrostatic field thus created the electrons lose part of their energy and protons or other positively ionized particles are accelerated. When equilibrium is finally established the two currents will just balance one another and at all distances from the source

$$\rho^+ v^+ = \rho^- v^-, \tag{9}$$

where ρ^+ and ρ^- are the average space densities

† Even the shower rays from lead, observed in cloud-chamber experiments at sea level, lie within about 30° of the primary direction and in air this spread would be considerably less.

[14] T. H. Johnson, Phys. Rev. **56**, 226 (1939).

[15] The fact that electrons at sea level do not produce mesotrons was already indicated by the shower studies of Janossy (Proc. Camb. Phil. Soc. **34**, 614 (1938)) and by the cloud-chamber photographs of Anderson and of Street and Fussell (privately communicated). The latter evidence is not entirely clear however since there have been instances where shower particles have failed to multiply as much as would have been expected if they were electrons. The independence of the soft and hard component primaries was pointed out by one of us on the basis of the symmetry of showers in 1935 (reference 16).

[16] T. H. Johnson, J. Frank. Inst. **220**, 25 (1935); Phys. Rev. **54**, 385 (1938). Protons have also been invoked on other grounds by various writers.

[17] C. G. Montgomery, D. D. Montgomery, W. E. Ramsey and W. F. G. Swann, Phys. Rev. **50**, 403 (1936).

[18] T. H. Johnson, Phys. Rev. **54**, 385 (1938); J. Wash. Acad., June, 1939.

of positive and negative particles and v^+ and v^- are their average velocities at the same distance. At great distances from the source the space charge density of the positives and negatives must also balance for otherwise potential differences irreconcilable with the observed passage of charged particles through space would develop. This consideration leads to the condition,

$$\rho_\infty^+ = \rho_\infty^-, \tag{10}$$

where ρ_∞^+ and ρ_∞^- are the charge densities at some suitably large distance from the source. Combining (9) and (10) we obtain

$$v_\infty^+ = v_\infty^-. \tag{11}$$

The ultimate velocities of the two types of particles are equal and their ultimate energies must therefore be in proportion to their respective rest masses. Thus the protons should have two thousand times more energy than the electrons and they alone should be able to reach the earth at the equator. In case (b) the considerations and the final result are identical with those of case (a) and the conclusion is the same regardless of which particle received the original energy. The ionic conductivity of intergalactic space and the production of positive and negative electron pairs add some complexities to these considerations which have not as yet been fully investigated, but which do not seem necessarily to invalidate the explanation of the proton component. Such considerations may also provide an explanation of the soft component primary electrons.

ACKNOWLEDGMENTS

Finally we wish to acknowledge the encouragement and financial assistance given to us by the Carnegie Institution of Washington upon the recommendation of ex-President Merriam and his Committee for the Coordination of Cosmic Ray Studies upon which so much of the success of this work has depended. We have also made full use of the facilities of Bartol Research Foundation in the preparation of the instruments, and for certain elements of the expenses. For this assistance we are indebted to Dr. W. F. G. Swann. The work in the Canal Zone was greatly facilitated by the earnest cooperation of Mr. James Zetek, Director of the Barro Colorado Island Laboratory and by Colonel S. B. Akin of the U.S.A. Signal Corps.

AUGUST 1, 1939 PHYSICAL REVIEW VOLUME 56

The Angular Dispersion of the Cosmic Radiation in the Upper Atmosphere Resulting from Deflections of Low Energy Particles in the Earth's Magnetic Field

T. H. JOHNSON
Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania, and Research Associate of the Carnegie Institution of Washington, Washington, D. C.

(Received May 29, 1939)

In order to estimate the diffuseness of the soft component of the cosmic radiation with respect to the direction of the primary particles for the interpretation of east-west asymmetry measurements a calculation has been made of the angular spread of secondary rays produced by deflections in the earth's magnetic field for the idealized case where the primary particles are incident unidirectionally from the vertical. Both radiation and ionization losses have been considered and it is found that at a depth of one meter of water rays whose energies exceed 15 Mev lie within thirty degrees and half of the intensity is within five degrees of the original direction. The beam broadens at higher elevations or when lower energies are included. The correction to the recent east-west asymmetry measurements at very high elevations because of this effect is wholly negligible.

IN the interpretation of cosmic-ray directional effects at sea level one may assume with close approximation that the rays which enter the instrument have the same direction as the pri-