Second Series *December 1, 1930* *Vol. 36, No. 11*

THE

PHYSICAL REVIEW

ON THE QUESTION OF THE CONSTANCY OF THE COSMIC RADIATION AND THE RELATION OF THESE RAYS TO METEOROLOGY

By Robert A. Millikan

California Institute of Technology

(Received October 23, 1930)

Abstract

Mean cosmic-ray intensities have been measured with much precision both at Pasadena, California (latitude 34) and at Churchill, Manitoba (latitude 59), the latter a distance of 730 miles from the North magnetic pole.

(1) The observed equality in these intensities indicates that these rays enter the earth's atmosphere as photons rather than as streams of electrons.

(2) Evidence is presented that the incoming rays are of a uniform intensity in all directions and in all latitudes, the small and apparently erratic fluctuations found by many observers at different stations arising simply from eruptions, waves, or ripples which change the thickness of the atmospheric blanket interposed between the source and the observer.

(3) The cosmic-ray electroscope thus acquires significance as a meteorological instrument.

(4) The influence of these rays in the maintenance of the earth's charge is considered.

I. Lack of Dependence upon Latitude

In our trip to the Bolivian High Andes in 1926 Dr. Cameron and I, by taking continuous observations at sea from latitude 34 north to latitude 17 south, and also by observing at altitudes of about 15,000 feet both in California and in South America, proved to our own satisfaction that the cosmic-ray intensities are the same the world over at a given elevation above sea level, and also that they are independent of the positions of any celestial objects *within the limits of our experimental uncertainty*, which we estimated at about 3 percent but which in our report[1] we gave as 6 percent so as to have a sufficient margin of safety. This result has been questioned by other observers, and theories have been advanced which required a variation of cosmic-ray intensities both with latitude and with the positions of celestial objects, and I myself have thought it entirely possible that there might be small variations depending upon these elements. It was therefore very important for the theory of the origin of these rays to have much more exact measurements upon these points than we had yet made.

Having now an electroscope which by virtue of carrying a pressure of

[1] Millikan and Cameron, Phys. Rev. **31**, 170 (1928).

450 pounds of air per square inch, and by virtue of other improvements in construction is fourteen times as sensitive as the one used in South America—it has not leaked a particle of air for more than two years—I have within the past fifteen months returned to the problem of studying variations with both latitude and sidereal time, since it is one of altogether fundamental importance for the understanding of the nature of these strange rays.

From the first we ourselves have thought the evidence satisfactory that these rays are ether waves of frequencies a thousand times and more those of the hardest x-rays, but others have thought that they might not be ether waves at all, but high-speed electrons instead.[2] If they were the latter, they would of necessity be influenced by the earth's magnetic field and should be stronger near the magnetic pole than at low latitudes, as is the case with other phenomena, such as the aurora, which depend upon the earth's magnetic field.

This summer I therefore went to the settlement which is much the nearest to the earth's north magnetic pole of any settlement on earth, namely, Churchill, 730 miles due south of the pole on the west side of Hudson's Bay—at present a construction camp where the Canadian Government is trying to make a three months summer harbor for the sake of bringing Manitoba and Alberta closer to Liverpool. It is estimated, for example, that eight cents a bushel can thus be saved on the transport of wheat from northwestern Canada to England. A construction train runs into Churchill once a week, crawling along at about 20 miles per hour over tracks laid partially on frozen swamps.

There, through the extreme courtesy of the Carter-Halls-Aldinger Engineering Co. Ltd., and also with transportation assistance for my 500 pounds of lead and other baggage from the Southern Pacific, the Canadian Pacific, and the Canadian National Railroads, I took observations continuously day and night for a week on the intensity of the cosmic rays, screening out the local rays with this shield of lead 7.6 cm (about 3 inches) thick. The aurora played brilliantly overhead on three of the six nights of observation, so that if cosmic rays and the aurora are phenomena that are in any way connected, the opportunity for bringing to light that connection could not have been better. The mean results, when compared with those similarly taken at Pasadena during the last week in July and the first in August show that *the cosmic rays have precisely the same intensity at Churchill, in latitude 59, as at Pasadena in latitude 34*, the mean results in the two places being 28.31 ions per cc per sec. and 28.30 ions per cc per sec., respectively, as measured in my particular electroscope. I think the error in these measurements cannot possibly be as much as 1 percent.

Table I gives the actual readings taken at six hour intervals, the rate of discharge in ions per cc per sec. during the six hours from midnight to 6 A.M. being labelled "night," that from 6 A.M. to noon being labelled "morning," that from noon to 6 P.M. being called "afternoon," and that from 6 P.M. to midnight "evening."

[2] Bothe and Kolhörster, Zeits. f. Physik **56**, 751 (1929).

TABLE I. *Comparison of cosmic ray intensitis at Pasadena, California, latitude 34, and Churchill, Manitoba, Latitude 59.*

Pasadena, July 26 to August 3, 1930

	Night		*Morning*		*Afternoon*		*Evening*	
	Ions cc/sec	Barometer inches	Ions cc/sec	Barometer inches	Ions cc/sec	Barometer inches	Ions cc/sec	Barometer inches
	29.77	29.13	29.19	29.14	29.96	29.10	30.08	29.09
	29.10	29.08	29.42	29.16	29.98	29.15	29.65	29.16
	29.27	29.19	29.49	29.18	29.70	29.15	29.33	29.12
	29.37	29.14	29.46	29.14	30.23	29.10	29.58	29.11
	29.56	29.16	29.22	29.16	29.52	29.13	30.24	29.13
	29.68	29.12	28.93	21.12	30.00	29.08	30.16	29.06
	29.42	29.09	29.52	29.10	29.56	29.09	29.94	29.11
	29.35	29.14	29.21	29.18	29.07	29.18	29.28	29.17
Means	29.44	21.13	29.31	29.15	29.75	29.12	29.76	29.12

Mean Ions cc/sec = 29.56 Mean barometer = 29.13.401 Corrected bar. = 29.14
Correction for local rays = 52.5×2.4% = 1.26.∴ Mean I cc/sec = 29.56 − 1.26 = 28.30
at mean barometer = 29.14.

Churchill, August 25 to September 1

	Night		*Morning*		*Afternoon*		*Evening*	
	Ions cc/sec	Barometer inches	Ions cc/sec	Barometer inches	Ions cc/sec	Barometer inches	Ions cc/sec	Barometer inches
	28.33	29.54	28.40	29.42	28.72	29.41	28.30	29.44
	28.24	29.49	27.88	29.58	28.46	29.66	28.53	29.77
	28.69	29.79	28.12	29.79	28.38	29.72	28.80	29.59
	27.82	29.47	29.10	29.35	29.17	29.27	29.25	29.26
	28.83	29.30	28.18	29.35			28.89	29.41
	28.57	29.45	27.63	29.51	28.06	29.61	28.39	29.63
	28.60	29.52	28.13	29.57	28.81	29.46		
Means	28.44	29.51	28.21	29.51	28.60	29.52	28.69	29.51

Mean ions cc/sec = 28.48 Mean barometer = 29.51 − 0.07 Corrected bar. = 29.44
Correction for local rays = 24.×2.4 = .58.∴ Mean I cc/sec = 28.48 − .58 = 27.90
Churchill ions cc/sec reduced to Pasadena barometer = 27.90 + 0.41 = 28.31
To compare with Pasadena observations 28.30

It will be noticed that the rays producing the observed 29 ions per cc per sec. inside the lead are almost pure cosmic rays, since the local rays amount to but 4 percent of the total at Pasadena and to less than 2 percent of the total at Churchill. The exact amount of the local rays in each position was determined by taking a reading without the lead screen and subtracting from this reading the cosmic-ray intensity as read off for the given elevation from our depth-ionization curve taken in snow-fed lakes with this same electroscope. The percentage of these local rays getting through the lead screen was found by making preliminary direct measurements with standard samples of uranium and thorium. It thus found that 2.4 percent of the local rays appear inside the lead. The zero of this electroscope, i.e., the reading when entirely screened from all rays, was 1.2 ions cc/sec, so that at Pasadena, for example, it was found that 27.1 out of the observed 29.56 ions per cc/sec were due solely to the cosmic rays. The recorded barometer readings are the means of those directly observed on my "precision Paulin" aneroid at the beginning and end of each run, and the indicated corrections were furnished me by the weather bureau stations at both Los Angeles and Churchill as read on their standard mercury barometers.

Since the portion of the sky from which the rays come at Churchill is quite different from that at Pasadena, the indications of these experiments are, then, First, *that the cosmic rays enter the earth uniformly from all portions of the sky*; Second, *that they consist as they enter the earth's atmosphere of ether waves, not of electrons.*

II. Lack of Dependence upon the Position of Andromeda or the Milky Way

But there are even more important conclusions than the foregoing that follow from the work thus far reported when it is taken in conjunction with the further experiments to be now considered.

When Dr. Cameron and I in 1925 proved[3] that the difference in the intensities of the cosmic rays at two levels in the atmosphere could be computed from the thickness of the blanket of air interposed between the two levels it of course followed that the intensity of the rays at the earth's surface must vary with barometric pressures, since these simply reflect approximately the varying weights of the atmosphere above. So when we had completed, more than a year ago, the full curve showing the variation of intensity with depth beneath the surface of the atmosphere, and could thus, with the aid of this curve, reduce the readings taken over days, or weeks, or months, to a common barometer-reading, I expected that the variability in the measured cosmic-ray intensities would disappear under this procedure. But continuous readings taken every six hours with very delicate instruments a year ago last summer seemed to spoil this expectation. They still showed fluctuations after careful reduction to a common barometer-reading, and for a while I thought these fluctuations came at such a time of day as to indicate that the Milky Way exerted a small positive influence upon the intensities of the rays. Although I mentioned to some of my colleagues my apparent finding that the Milky Way might increase the intensity of the rays by perhaps a percent by its presence overhead, I made no publication of even such a small dependence of cosmic-ray intensity upon stellar-time, for I wished first to extend the observations to different times of the year when the Milky Way would be overhead at widely different times of day.

Such a prolonged and continuous following of the changes has now brought to light the fact that neither the Milky Way or the nearest of the spiral nebulae Andromeda, nor any other celestial object has anything to do with these changes, but rather that they are a diurnal affair occurring at the same time of day at widely different seasons of the year and having a connection with the diurnal barometric cycle. It is well known that this diurnal cycle carries the barometer—especially in warm regions free from summer storms—through a minimum late every afternoon and a maximum in the morning. The cosmic-ray intensities at Pasadena go through a *maximum every afternoon* and a *minimum every morning* even after corrections have been made to bring the readings to a common pressure. Table II exhibits these facts clearly, the readings from July 14–19 are entirely consistent with

[3] Millikan and Cameron, Phys. Rev. 5, 851 (1926).

TABLE II. *Cosmic ray intensities.*

Date	Night		Morning		Afternoon		Evening	
July 14 to 19, 1930								
	12:08–8:52	29.81	9:11– 1:08	30.07	1:20–6:10	30.14	5:18–11:52	30.21
	12:07–7:47	29.69	8:00– 2:02	29.33	2:13–6:06	30.16	6:24–11:56	29.53
	12:30–8:12	29.62	8:22–12:25	29.77	12:33–4:22	31.15	6:20–12:15	29.87
	11:40–6:03	29.61	6:13–11:06	29.85	11:17–3:41	29.77	4:31–11:25	30.03
	10:26–1:44	29.94	9:31– 1:57	29.62	2:07–6:20	30.77	3:52–10:16	29.83
	1:53–9:22	29.63						
Means		29.71		29.73		30.39		29.89
July 19 to 27, 1930								
	12:38–6:39	29.78	6:40–12:20	29.72	12:32–6:02	30.01	6:30–12:24	29.53
	12:32–6:02	29.43	6:19–12:32	29.67	12:43–6:18	30.08	6:14–12:16	29.99
	12:40–6:45	29.85	7:08–12:38	29.72	12:48–6:26	29.82	6:28–12:26	30.09
	12:28–6:39	29.99	6:58– 1:22	30.12	1:53–6:32	30.69	6:36–12:06	30.04
	12:19–6:45	29.93	6:55–12:29	29.91	12:38–6:34	30.13	6:43–12:07	30.42
	12:33–6:41	29.42	6-57–12:32	29.75	12:42–6:33	30.35	6:46–12:22	30.35
	12:11–6:22	30.10	6:33–12:44	29.57	12:55–6:30	30.26	6:44–11:58	30.22
	12:03–5:57	29.43	6:09–11:55	29.78	12:05–6:05	30.35	6:44–11:50	30.35
Means		29.74		29.78		30.21		30.12
	Milky Way overhead all this period		Milky Way overhead most of this time		Milky Way entirely out of sight		Milky Way partially overhead	
Oct. 6 to 12, 1929								
10/6/29	11:56–8:05	30.09	8:25– 2:14	30.01	2:22–6:49	30.77	6:54– 1:04	30.52
10/7/29	1:11–10:24	30.30			10:33–6:22	30.53	6:30–11:40	30.65
10/8/29	11:52–8:12	20.21	8:13– 1:47	30.08	1:57–7:07	30.54	7:16–12:21	30.34
10/9/29	12:30–9:04	29.61	9:19– 2:15	29.90	2:26–6:50	30.63	6:59–11:69	30.20
10/10/29	12:07–9:10	29.88	9:21– 3:30	30.37	3:40–7:00	30.54	7:10–11:51	30.30
10/11/29	12:04–8:57	29.84	9:09– 2:04	29.73	2:15–6:20	30.80	6:29–11:57	30.24
10/12/29	12:10–9:09	29.92	9:21– 2:22	30.32				
Means		29.98		30.07		30.63		30.37
	Milky Way overhead most of this time		Milky Way entirely out of sight		Milky Way partially overhead		Milky Way overhead all this period	

those taken from July 19–27, the "night" readings and the "morning" readings being in both cases lower than the "afternoon" and "evening" readings. Further, the night readings are the most consistent among themselves because the atmosphere is then in its most quiet condition. As indicated two-thirds of the way down the table the Milky Way was here entirely out of sight *when the cosmic ray intensities were at their afternoon maximum.* I at first thought that this must mean that the Milky Way, instead of exerting a positive influence as had been before suspected must instead act as an absorbing screen for the cosmic rays. But, as shown at the bottom of the table, in October 1929 I had taken a similar series of readings. The Milky Way had then moved forward about 6 hours, so that it was completely out of sight in the *morning* instead of the afternoon, *and yet the relation of the morning and afternoon readings had not been altered a particle by this fact.* That the readings are all a little higher in October, 1929, than in July, 1930, has no significance save that I was reducing to a different barometer reading at the former time. Table II yields quite exact and unambiguous proof, then, *that the Milky Way has no influence whatever, and therefore that the cosmic rays must originate "in the depths of space beyond the Milky Way."*

Table III shows again the same relations. The day was here divided into seven periods instead of into four, the time at the top of each column being merely the median clock-reading for the period. Here too, it is seen that the maximum is in the late afternoon and the minimum at night or in the early morning.

TABLE III. *Cosmic ray intensities.* (Observations August 1 to August 9, 1930).

12:40 P.M.		3:30 P.M.		6:15 P.M.		9:45 P.M.	
10:22–4:05	29.45	1:20–6:51	29.99	3:34–8:21	30.42	6:14–12:00	30.00
10:07–3:25	30.20	12:46–6:35	29.79	3:25–9:19	30.05	7:00–12:45	29.60
10:01–3:17	29.72	12:57–6:45	30.07	4:00–9:29	29.85	6:33–12:27	29.81
10:23–3:23	29.67	12:43–6:14	29.75	4:13–9:30	29.65	6:56–12:56	30.24
10:35–4:40	29.50	12:57–3:50	29.85	4:07–9:53	30.05	6:22–10:40	29.97
10:06–2:29	30.01			3:33–7:58	30.56	8:32–12:42	29.87
11:11–3:57	29.83			3:28–8:29	30.09	7:25–11:55	30.49
9:56–3:25	29.90			3:21–8:00	29.93	8:36–12:30	29.40
				2:47–7:53	29.57	8:11–12:22	29.80
Means	29.79		29.89		30.02		29.91
Milky Way a little in		Milky Way nearly out		Milky Way entirely out		Milky Way out	
3 A.M.		7:45 A.M.		9:45 A.M.			
12:11–6:28	29.69	5:53–11:03	29.95	6:33– 1:05	29.89		
12:55–6:43	29.66	5:34–10:16	29.52	6:50–12:48	29.73		
12:42–6:36	29.86	5:25–10:25	29.72	6:47–12:35	29.55		
11:50–5:47	29.91	5:10– 9:51	29.69	7:04–12:35	29.64		
1:03–6:53	29.52	5:59– 9:57	29.62	6:09–11:56	29.79		
10:51–5:12	29.65	4:32– 9:46	29.75				
9:43–3:36	29.62	4:10– 9:54	29.46				
12:53–6:45	29.50	3:47– 9:16	29.56				
7:45–3:53	29.51						
12:09–5:47	29.90						
12:41–6:55	29.89						
12:39–5:24	29.20						
12:32–5:13	29.98						
12:38–5:10	30.07						
Means	29.71		29.66		29.72		
Milky Way in		Milky Way in full		Milky Way mostly in			

The sort of consistency and precision in electroscope readings here attained is rather nicely shown by Tables II and III, which reveal that in three different sets of observations taken over three different groups of days the three "night" mean-readings were 29.71, 29.74, and 29.71, while the three morning mean readings were 29.73, 29.78, 29.72. The afternoon and evening readings fluctuate more because the atmosphere is then more disturbed.

III. EXPLANATION OF FLUCTUATIONS

The reason for the behavior shown in Tables II and III is now quite clear. As the sun rises and begins to heat the earth the barometer begins to rise, not at first because there is any larger weight of atmosphere above it, but solely because the temperature of the air, partially confined by its viscosity and inertia, is rising. Before night the column of air over the heated area has expanded upward, flowed over at the top, and left a miniature terrestrial "sun spot" or hole in the atmosphere through which the cosmic rays then reach the earth in greater intensity merely because the air-blanket has been partially removed locally by the heated spot.

In a word, the barometer is an instrument that responds both to the *temperature* and to the *weight* of the superincumbent air, i.e., to a mixture of static and kinetic conditions, while the cosmic-ray electroscope reflects only the *mass* of the superincumbent air, and is quite independent of temperature, or of kinetic effects of any kind. *The cosmic-ray electroscope is thus a simpler and a more fundamental instrument than the barometer.* I expect it to be an aid in bringing about advances in the as yet little developed science of meteorology, and ultimately to find a place in meteorological stations. The air is simply an absorbing blanket interposed between us and a constant source of radiation coming into the earth uniformly from all directions. Every eruption, or wave, or ripple in that blanket is accurately reflected by the cosmic-ray electroscope of the type here used. The changes that it reveals are considerably larger than the changes revealed by the barometer, because it cares nothing about the temperature, but only about the mass of the interposed layer of air, while with the barometer a rise in temperature often masks the thinning of the air-blanket above. The two instruments between them furnish more information about the condition of the upper air than either one of them alone can do. The afternoon barometer minimum, corresponding to a mean drop of one-tenth inch of mercury, or one-third percent, may be accompanied by a cosmic ray rise of two percent, as Tables II and III show.

IV. Clearing up of Former Discrepancies

The fourth result to which I would call attention is that the proof that the cosmic rays that strike the atmosphere are all ether-waves, rather than a mixture of ether waves and high speed electrons, carries with it the conclusion that the rate of ionization within a vessel sent to the top of the atmosphere should not be a maximum at the top as we have heretofore assumed, but should pass through a maximum somewhere below the top. This removes the apparent contradiction between the early results of Hess and Kolhörster (1911–1914), who went up in manned balloons, and Bowen and myself (1922), who sent up recording electroscopes with pilot balloons to much higher altitudes. We obtained a very much smaller *mean* absorption coefficient than they did, and this is precisely what we should have done in view of this aforementioned maximum. This result also brings to light new evidence for the correctness of the interpretation made by Dr. Cameron and myself that the cosmic rays are due to the continuous formation "in the depths of space" of the common abundant elements helium, oxygen, silicon, and iron out of hydrogen; for, before these ether waves get into equilibrium with their train of secondary electrons they should show absorption coefficients of the same order of magnitude as, but *somewhat smaller than*, those computed for them by the Einstein equation, Aston curve, and the Klein-Nishina formula. This is exactly what they do show, and they show this departure least for the rays corresponding to the formation of helium, for which the difference is quite small, and most for those corresponding to the formation of iron. This, also, is exactly in accord with our observations, reported to the Academy at its fall meeting a year ago.

V. Cosmic Rays and Atmospheric Electricity

About forty percent of the ionization in the atmosphere at the earth's surface over the land is due to cosmic rays and sixty percent to the radioactive substances contained in the earth, but at the altitude of Pike's Peak (14100 feet) we have found the cosmic rays three times as intense as at sea level, and this checks roughly with Hess' and Kolhörster's observations made as early as 1911 to 1914. But at altitudes above say two thousand feet the influence of rays from the earth in producing atmospheric ionization has become negligible, the cosmic rays alone being here effective, *so that practically the whole ionization of the atmosphere above its surface layer and below the great altitudes at which the Kennelly-Heaviside layer is found is due to the cosmic rays.* These rays must therefore exert a preponderating influence upon atmospheric electrical phenomena.

We have heretofore had considerable difficulty in finding a mechanism by which the earth can maintain its well-known negative charge,—a charge sufficient to produce a more or less constant potential gradient, near the surface, of some 100 volts per meter. The cosmic rays, by detaching negative electrons from the molecules of the atmosphere and hurling them with enormous energy into the earth, must contribute somewhat toward the maintenance of this gradient; but they are much too few in number, indeed, of an entirely wrong order of magnitude, to account for the observed effects. Indirectly, however, they assist greatly in maintaining the earth's charge, the mechanism being presumably somewhat as follows:

The ionization of the upper air by the ultraviolet light from the sun is undoubtedly very large, enormously larger than that due to cosmic rays, as is shown by the existence of the Kennelly-Heaviside layer. The result of this ionization, whatever its cause, ultraviolet light, cosmic rays, or what not, is to free, in the higher stretches of the atmosphere, the lightest possible gas, namely, an electron gas, about 1/50,000th the weight of nitrogen gas, and this, because of its extreme lightness and mobility, at once expands upward, or *tries to do so*, until stopped by the field that such expansion itself creates, the greater chance of attachment of the electrons that diffuse downward accentuating this process. This field is of course of such sign as to tend to drive all the negative ions formed within it, and especially the attached negatives which have no tendency to diffuse upward, in toward the earth, and to hold the positives in the air above them. In other words, the outermost layers of the atmosphere in view of this influence, should have an excess of negatives, the next lower layers an excess of positives, and below that there should be a layer in which negatives are again in excess.

Now, no one has gone far enough up to find the aforementioned outermost layer, but Wiegand[4] and Idrac[5] both report altitude observations in which the field drops from 100 volts per meter at the surface to nearly zero at 8 kilometers and then, in the region between 8 and 12 kilometers, rises in such a way as to indicate an excess of negatives, followed by an excess of positives between 12 and 19 kilometers, where the field has again dropped to zero.

Now water vapor is found up to 12 kilometers, and wherever below that it is rising, expanding and condensing on ions, it will condense, according to the C. T. R. Wilson effect, only on the negatives, although a droplet may afterward catch a positive by the diffusion process. Furthermore, atmospheric dust is usually found predominently negatively charged. Negative capture seems, then, to be *strongly* favored by the C. T. R. Wilson effect, and to be somewhat facilitated by the excess of negatives between 8 and 12

[4] Wiegand, Ann. d. Physik **66,** 261 (1921).

[5] Idrac, Comptes rendus **182,** 1634 (1926).

kilometers, and also by the greater tendency of negatives, due to greater mobility, to collect on dust. After such capture gravity of course pulls this negatively charged dust and water vapor into the earth.

This gravitational effect on heavy, negatively charged carriers is, then, what creates a portion at least, of the negative gradient near the surface, a field that actually decreases rapidly with altitude, and if this theory is correct, should be reversed at high altitudes. A "gravity" theory of the maintenance of the earth's charge is not at all new, though there may be some elements of novelty in the foregoing elaboration of it. The purpose here is to point out the very important role that the cosmic rays play in it, since they must furnish practically all the atmospheric ions between the thin layer next the earth and the Kennelly-Heaviside layer.

VI. Summary

In summary, then, we have presented convincing evidence

(1) That the cosmic-ray intensities are independent of latitude.

(2) That the cosmic-ray intensities are independent of sidereal time.

(3) That the rays are constant all over the earth's surface, but that the fluctuations observed by many experimenters merely reflect changes in the thickness of the interposed atmospheric blanket.

(4) That the cosmic-ray electroscope may be of use in meterology.

(5) That the cosmic rays enter the atmosphere as ether waves or photons, and hence produce their maximum ionization, not at the surface of the atmosphere, but somewhat farther down.

(6) That the observed cosmic-ray effects are all in all good general agreement with the predictions of the Klein-Nishina formula, thus lending support to the view that the cosmic rays are due to atomic synthesis going on "in the depths of space."

(7) That the cosmic rays are a very important factor in atmospheric electrical effects, especially in the maintenance of the earth's negative charge.