The time necessary to empty or to fill the cylinder is (if $w=i_0V$)

$$T=W/W_r=(3\pi^{\frac{1}{2}}rl/2c^{\frac{1}{2}})(i_0/V)^{\frac{1}{2}}.$$

Putting $V=\frac{1}{3}\times 10^8$ e.s.u. and $i_0=2\times 10^{-10}$ e.s.u. (which corresponds to the intensity at the top of the atmosphere) and $l/2=r=1000$ light years (10^{21} cm), we find $T=10^{11}$ years, which is more than the age of the universe! Further, if we calculate the absorption in interstellar matter within the cylinder, we find that it is many times as large as W_r.

Let us now suppose that our earth is situated within the cylinder. We have found that unless the values of i_0 and V are *many* times larger at the surface of the cylinder than the values measured at the top of the earth's atmosphere (which is improbable), the current through the surface can neither fill the cylinder to the intensity measured here, nor compensate for the absorption losses. Consequently, *cosmic radiation must have been generated within the cylinder.*

This indicates that *most of the cosmic radiation we obtain here on earth has been generated within a distance of less than 1000 light years.*[4] (The thickness of the galactic system is about 10,000, the diameter about 100,000 light years.)

[4] Compare, H. Alfvén, Comptes rendus **204**, 1180 (1937).

MARCH 1, 1939 PHYSICAL REVIEW VOLUME 55

Long Period Variations of Cosmic Rays

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(Received November 14, 1938)

With the data from the Carnegie Institution's Model C cosmic-ray meters at four widely separated stations, a study of yearly variations and of a variation of cosmic-ray intensity with a 28-day period, apparently connected with the sun's rotation, has been made. The amplitude of the first annual harmonic with a maximum in colder months varies from 2.15 ±0.06 percent at Cheltenham, 38°.7 N to 0.15±0.03 percent at Huancayo, 12°.05 S. The amplitude of a 27.9-day period is 0.18 percent. Values of the atmospheric temperature coefficient at the different stations are given. The results give some support to Blackett's theory that the annual variation is due to changes in elevation of the barytron producing layer with the thermal expansion of the atmosphere. No other essential relationship between observed annual variation of cosmic-ray intensity and meteorological or astronomical phenomena has shown itself.

IN ADDITION to the well-known daily variation of cosmic-ray intensity, evidence has been given for the existence of seasonal variations and of variations following the rotation of the sun.[1–7] With the data that has come from the Carnegie Institution's Model C cosmic-ray meters[8] at various widely separated stations, a more thorough study of such variations has been possible.* For the periods during which the data are available, it is found that in the northern and southern temperature zones the cosmic-ray intensity has been significantly greater during the winter months. Seasonal variations occur likewise in the tropics, but here a six-month peri-

[1] J. Clay, Proc. Roy. Acad., Amsterdam **23**, 711 (1930).
[2] E. G. Steinke, Zeits. f. Physik **64**, 48 (1930).
[3] J. A. Priebsch and R. Steinmaurer, Gerlands Beitr. z. Geophys. **37**, 296 (1932).
[4] V. F. Hess, Terr. Mag. **41**, 345 (1936).
[5] J. A. Priebsch and W. Baldauf, Ber. Wien Akad. IIa, **145**, 583 (1936).
[6] A. H. Compton and R. N. Turner, Phys. Rev. **52**, 799 (1937).
[7] B. F. J. Schonland, B. Delatizky and J. Gaskell, Terr. Mag. **42**, 137 (1937).
[8] A. H. Compton, E. D. Wollan and R. D. Bennett, Rev. Sci. Inst. **5**, 415 (1934).

* *Note added in proof:* S. E. Forbush, has just published (Phys. Rev. **54**, 975 (1938)) an independent analysis of the same data, following a different method. He finds seasonal variations closely similar to those here reported, and in addition world-wide changes closely correlated between the various stations. Forbush pays slight attention to the variations following the solar rotation.

odicity becomes relatively prominent. There is likewise found a significant variation of cosmic-ray intensity with a 28-day period, which is probably to be associated with the time of the sun's rotation.

Earlier studies by Clay,[1] Steinke,[2] and Priebsch and Steinmaurer[3] indicated seasonal changes of several percent with a maximum in summer. The more extensive study made by Hess,[4] Priebsch and Baldauf,[5] with data obtained on the Hafelekar in Austria during 1932–34, however, showed changes of about the same magnitude but with the maximum in winter. This result was confirmed by Compton and Turner,[6] in their studies of the cosmic rays on the Pacific Ocean during 1936–37, where the maximum was found to occur in the winter in both hemispheres. The data of Compton and Turner were, however, of lower statistical weight, and obtained under considerably less favorable experimental conditions, than those used in the present investigation.

Significant evidence for a period of about 27 days in the cosmic-ray data collected on the Hafelekar has been presented by Hess[4] and Graziadei.[9] It has seemed worth while to extend this analysis, with a different method, to the more complete data now available. Their findings are definitely confirmed, and it has been shown that the effect is world-wide.

TABLE I. *Annual variation of cosmic rays at four stations in percent of mean ionization.*

Station	First Harmonic (12-mo. period) Amp.	First Harmonic Phase	Second Harmonic (6-mo. period) Amp.	Second Harmonic Phase
Cheltenham, 38°.7 N. 76°.8 W. mean bar., 760 mm	2.15 ±0.06	84° ±2°	0.58 ±0.06	245° ±6°
Teoloyucan, 19°.75 N. 99°.2 W. mean bar., 585 mm	0.86 ±0.04	42° ±3°	0.53 ±0.04	265° ±5°
Huancayo, 12°.05 S. 75°.3 W. mean bar., 515 mm	0.15 ±0.03	163° ±13°	0.18 ±0.03	307° ±11°
Christchurch 43°.5 S. 172°.6 E. mean bar., 760 mm	0.27 ±0.04	205° ±9°	0.36 ±0.04	53° ±7°

[9] H. Th. Graziadei, Ber. Wien Akad. IIa, **145**, 495 (1936).

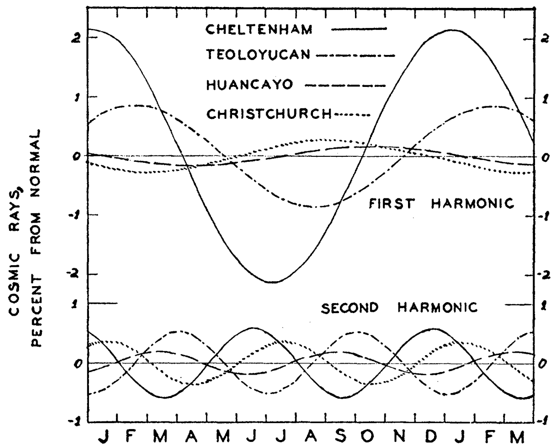

FIG. 1. First and second harmonics fitted to monthly mean ionization.

Seasonal Variation of Cosmic-Ray Intensity

The data used in this analysis were obtained from meters stationed at Cheltenham, Maryland; Teoloyucan, Mexico; Huancayo, Peru and Christchurch, New Zealand. They cover, respectively, the periods, from March, 1937 through February, 1938 at Teoloyucan, from July, 1936 through August, 1937 at Huancayo, and from April through December, 1936, and from April through June, 1937 at Christchurch. These meters measure the ionization in argon by cosmic rays that have been filtered through the equivalent of 12 cm of lead.

In analyzing the data, daily mean ionizations corrected to normal barometric pressure were tabulated, and monthly means were calculated. Previous studies had shown that no correction was required for the slightly variable temperature of the meter. Monthly mean ionizations, centered at mid-months, were used in obtaining the Fourier coefficients for the first and second harmonics. The calculations were made according to Duvall's formulae,[10] using for the probable error his function ϵ_y. Table I gives the amplitudes as thus obtained for the first and second harmonics, expressed in percentages of the total, or absolute, cosmic-ray ionization at each station. The tabulated probable errors for each place are the arithmetic means of those two months for which the probable errors were highest and lowest.

[10] C. R. Duvall, Terr. Mag. **32**, 151 (1927).

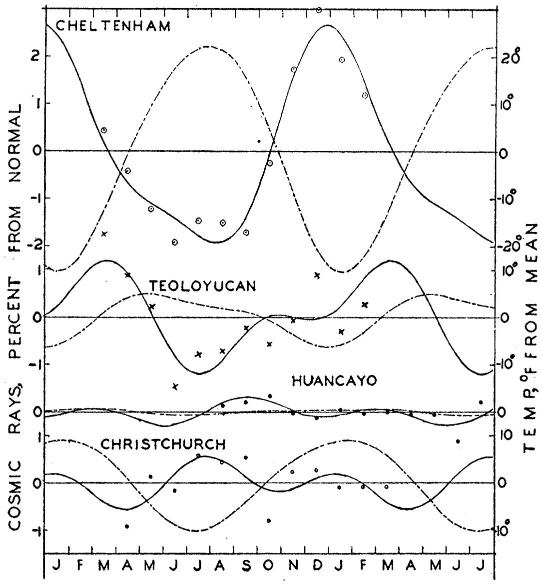

FIG. 2. Sum of first and second harmonics fitted to monthly mean ionization due to cosmic rays (heavy lines) and the sum of first and second harmonics fitted to monthly mean temperatures (broken lines).

At Huancayo the monthly mean ionization decreased almost linearly. Hence a least-squares line was fitted to the fourteen months data from July 1936 to August 1937, and the harmonic analysis was applied to the central twelve deviations from this line. For the other stations, no such adjustment was required.

Figure 1 shows the first and second harmonics at the various stations. In Fig. 2 are shown the sums of these two harmonics, and the datum points from which they are calculated. Likewise in this figure are given the sums of the first two harmonics of the mean temperature[11] at, or near, these stations.

Cosmic-Ray Intensity and External Temperature

The maxima of the sum of the first and second harmonics at Cheltenham and Christchurch come approximately during the middle of the cold months at the respective places. At Teoloyucan and Huancayo, where the second harmonics play as important a part as the first, and where the seasonal temperature changes are small, the cosmic-ray maxima occur during the spring, i.e., about March 21, at Teoloyucan, and September 23 at Huancayo.

Nevertheless, except at Cheltenham, no significant correlation is found between the monthly mean cosmic-ray intensity and monthly mean atmospheric temperatures. The results of this correlation study are shown in Table II. In this table the calculation from Huancayo is omitted because the seasonal temperature variation is only about 0.5°C from the mean, so that any correlation with the temperature could only be fortuitous.

A comparison with Compton and Turner's[6] results from the Pacific Ocean shows that where the correlation coefficient is significant (Cheltenham) the magnitude of the atmospheric temperature coefficient agrees satisfactorily with their finding. It is apparent, from the present data however, as they had indeed suspected, that in other places the temperature of the atmosphere does not serve even as an approximate index of the cosmic-ray intensity. Moreover, though the temperature changes from week to week and from day to day at Cheltenham are quite large, Forbush[12] shows that over such short periods no significant correlation with temperature exists. It follows that neither local changes in temperature nor those associated with transient cyclones affect appreciably the cosmic-ray intensity. This conclusion is in no way contrary to the evidence here presented for a real temperature coefficient when the interval is extended over a month or a year.

TABLE II. *Atmospheric temperature coefficient of cosmic-ray ionization (reduced to standard barometer).*

Location	Coefficient Percent	Correlation Coefficient
From the data of this paper		
Cheltenham	-0.15 ± 0.02	-0.90 ± 0.04
Teoloyucan	-0.08 ± 0.09	-0.19 ± 0.19
Christchurch	(-0.05 ± 0.02)	(-0.31 ± 0.20)
From the data of Compton-Turner		
Vancouver	-0.22 ± 0.02	-0.85 ± 0.04
Auckland	-0.16 ± 0.04	-0.47 ± 0.15
Sydney	-0.10 ± 0.02	-0.67 ± 0.10
At Sea	-0.18 ± 0.01	-0.68 ± 0.03

[11] Temperatures obtained at Cheltenham from U. S. Monthly Weather Review (monthly means from March 1936 to February 1937), Mexico City from Mexican Weather Reports (monthly means from 1878 to 1924), Arequipa, Peru (monthly means from 1892 to 1912), and Christchurch, New Zealand (monthly means from 1864 to 1923).

[12] S. E. Forbush, Terr. Mag. 42, 1 (1937).

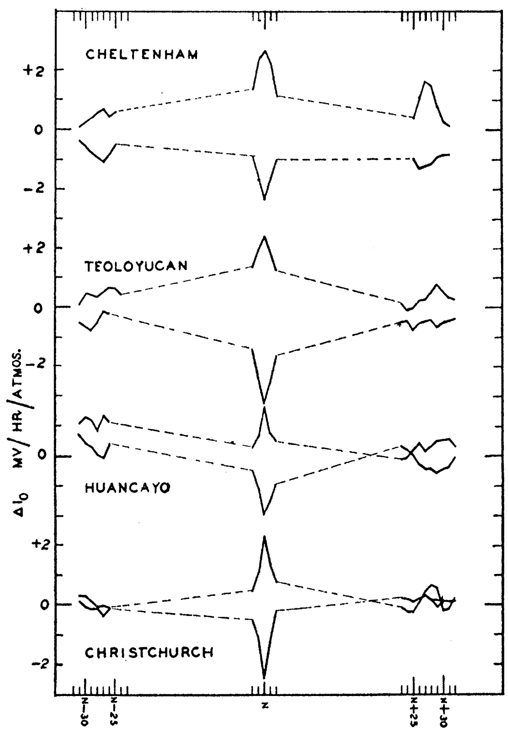

FIG. 3. Curves showing the occurrence of the first positive and negative pulses after an arbitrarily chosen pulse for highest or lowest values of daily mean cosmic-ray intensity at each station.

Blackett[13] has made a theoretical calculation of the temperature coefficient of the cosmic-ray intensity, using the hypothesis of the instability of the barytron as discussed by Euler and Heisenberg.[14] For the north temperate zone he estimates by two different methods, $\alpha = -0.16$ and $\alpha = -0.20$ percent per degree centigrade. Near the equator he mentions that the temperature coefficient should be considerably less. For the south temperate zone, because data regarding the temperature of the atmosphere at high altitudes for the various seasons are lacking, no quantitative prediction is made. It will be noted that these estimates are in good general agreement with the values listed in Table II. In addition to good quantitative agreement in the north temperate zone, we see an indication of the predicted decrease in α near the equator in the data from Teoloyucan. The value from Christchurch has low significance, since it is based on only nine consecutive months omitting the summer period. It is also possible that at this latitude, where land areas are rare, the temperature of the upper air may change but little with the season.

It is noteworthy that this analysis confirms to some five times higher precision the reported[6] absence near the equator of a yearly period with maximum at perihelion (January 1), such as should occur if a part of the rays come directly from the sun. Thus at Huancayo, from Table I, it will be seen that the annual variation with maximum on January first has an amplitude of 0.04 ± 0.03 percent, as compared with an anticipated amplitude of about three percent for a solar component.[6] Thus probably not more than one or two percent of the cosmic rays observable at the equator come from the sun.

Similarly, this analysis fails to reveal any evident affect ascribable to shielding by the action of the sun's magnetic field. This might have been expected to reduce the mean world intensity of cosmic rays when the earth is close to the sun on January first. The average of all data would be a very small change of opposite sign.

The result is that the present analysis shows definite seasonal variations at the locations and for the periods investigated. Though at Cheltenham there is a close correlation with atmospheric temperature, it is clear that there is no direct dependence of cosmic-ray intensity on transient changes of air temperature. The data give some support, however, to Blackett's view that this seasonal variation of cosmic rays is caused by the changing altitude of the barytron-producing layer with the thermal expansion of the atmosphere.

Twenty-Seven-Day Period in Cosmic-Ray Intensity

When the daily mean ionization as observed at the different stations was plotted against time, there occasionally appeared variations having a period of roughly a month which could be followed through several cycles and then gradually became confused with other variations. This suggested the search for a variation of a quasi-periodic type such as has been reported by Hess[4] and Graziadei.[9]

[13] P. M. S. Blackett, Phys. Rev. **54**, 973 (1938).
[14] H. Euler and W. Heisenberg, Ergebn. d. Exakt. Naturwiss. **17**, 1 (1938).

Chree's method,[15] developed in his studies of the 27-day period in international magnetic character numbers, was followed. This method consists in selecting in each month the five days showing the highest daily mean cosmic-ray intensity. Let the date of the maximum be indicated by n. Then the daily mean values for the dates $n+23, \cdots 32$ and for $n-23, \cdots 32$ are plotted. If a real period of roughly 27 days exists, the resulting graph should show greater than normal intensity, with a maximum near $n+27$ and $n-27$. If the period sought for does not exist, there should be equal probability of finding greater or less intensity than average for the month on the dates $n\pm27$. Similarly, the five days having the lowest daily mean intensity during the month are selected, determining the date of observed minimum m. We should then anticipate less than normal intensity near $m\pm27$ days if there is a true period of about 27 days.

Figure 3 shows the resulting values at dates near $n\pm27$ and $m\pm27$ as averaged over all the data available from our four stations. It is significant that in every one of the eight cases the intensity on the date $n\pm27$ (or 28) is greater than on the date $m\pm27$ (or 28). Had there been no periodicity of approximately this length, whether the former values would be the larger would be a matter of chance, with a probability for a favorable result eight times out of eight of one in 256. It is thus evident that the periodicity under investigation is a real one.

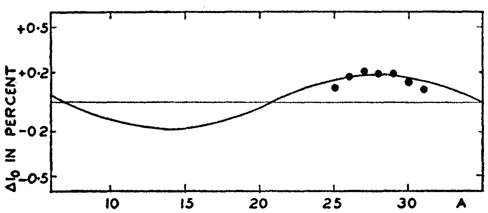

FIG. 4. Cosine curve drawn through the points $a=25$ to $a=31$ in order to determine the exact period of 27 or 28-day variation in cosmic-ray intensity.

In order to determine more exactly the length of the period, the departures ΔI_0 of the daily mean value of I_0 have been averaged over the a's for the dates $n+a$, $n-a$, $m+a$ and $m-a$, reversing the sign of the ΔI_0's for $m+a$ and $m-a$. Figure 4 shows the result. It will be noted that the points for $a=25$ to $a=31$ lie roughly on the first peak of a cosine curve whose period is about 27.9 days and whose amplitude is 0.18 percent.

The two prominent astronomical periods of approximately this length are (1) the sidereal month, of 27.32 days, and (2) the period of the sun's rotation relative to the earth.[16] This period varies from about 26 days at the equator to 32 days at 80°, with a mean value given as about 27.1 days. The lack of persistence of the quasi-periodic changes that we are discussing suggests that they should not be associated with something so definite as the revolution of the moon. On the other hand, this characteristic fits well with the view that they may be associated with some surface activity on the sun, such as sun spots. The known correlation between the appearance of sun spots and terrestrial magnetic disturbances lends support to this suggestion.

The writer wishes to express his sincere thanks to Professor A. H. Compton for his inspiring guidance and for his continuous interest in this investigation. The writer also wishes to acknowledge his indebtedness to Mrs. Ardis T. Monk for useful suggestions and help in calculations. Grateful acknowledgment is made to Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, for supplying most of the records for this investigation.

[15] C. Chree, Phil. Trans. Roy. Soc. **A212**, 75 (1913); C. Chree and J. M. Stagg, Phil. Trans. **A227**, 21 (1927).

[16] Cf. *International Critical Tables* (1926), Vol. 1, p. 392.