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Relation of Frequency of Occurrence of Small Cosmic-Ray Bursts to Areas of Sunspots and Other Variables*

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This paper deals with the frequency of occurrence of small cosmic-ray bursts represented by 2.9 to 3.6 millions of pairs of ions in a heavily shielded chamber of 13.3 liters effective volume containing air at 160 atmospheres. An earlier investigation by Chree's method of superposed epochs had indicated 27-day recurrences in fluctuations of the frequency, somewhat comparable to the 28-day recurrences found in the cosmic-ray intensity as represented by the daily average ionization current in the same chamber corrected for bursts and for variations in atmospheric pressure. Here the analysis is continued to investigate the possibility of a dependence of the small-burst frequency upon terrestrial magnetic character and sunspot area comparable to that found for the C-R intensity, as well as the relation between the latter and the burst frequency. While some positive correlation between the burst frequency and the corrected ionization current is indicated, the relation does not appear to be intimate. Pulses in the burst frequency representing deviations of more than seven percent from the mean are found associated with the primary pulses in sunspot area, particularly the negative pulse, and roughly in phase opposition. No clear-cut relation to the magnetic character is indicated. A large negative barometric coefficient is found for the burst frequency, at least for the early months of the year, amounting to about −3 or −4 percent per mm Hg. An explanation of the observations is suggested in terms of the production of the small bursts and the (corrected) ionization in the shielded chamber through the agency of different types of radiation.

IN a recent paper,[1] the author reported a preliminary investigation of the frequency of occurrence of certain small cosmic-ray bursts occurring in a shielded, high pressure chamber at Boulder (lat. 40°N; long. 105°16′W; alt. 5440 ft.) by Chree's "superposed-epoch" method of analysis. The analysis was carried out for the limited range of day numbers from −45 to +45. Irregular pulses were found both preceding and subsequent to both positive and negative primary pulses. Both subsequent and preceding difference curves and the combination difference curve displayed pulses with peaks at about 27 days preceding and subsequent to the primary pulses. These secondary pulses amounted to about 3 or 4 percent of the average frequency of approximately 37 small bursts per day (corrected for grounding time) and about 10 percent of the primary pulses.

As explained in the earlier paper,[1] the investigation was limited to bursts producing deflections between 1.0 and 1.25 mm on the photographic record, representing 2.9 to 3.6 millions of pairs of ions in the chamber. The effective volume of the chamber was 13.3 liters, and it contained air at a pressure of about 160 atmospheres. The thick-walled steel chamber was surrounded by 5 inches of lead, and was further shielded by the stone walls of the building in whose basement it was located. Since the ionization chamber[2] was formed by excavating a spherical cavity from a solid steel cylinder, the shielding provided by the chamber walls varied from a little over 7 cm of steel for vertical rays through a maximum of

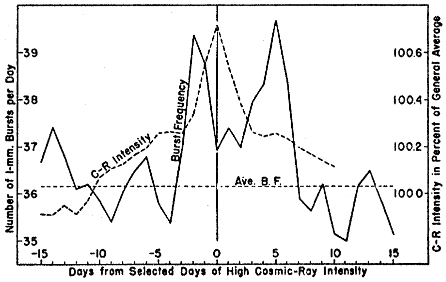

FIG. 1. Primary positive pulse in the cosmic-ray intensity as measured by the corrected ionization current, together with corresponding pulse in frequency of 1-mm bursts. Zero days are the five in each month of greatest cosmic-ray intensity as indicated by the average current. In this and subsequent diagrams, the number of 1-mm bursts designated is the number observed in 24 hours without correction for the grounding period of 2 minutes in each hour.

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* A preliminary report of this work was given at the meeting of the American Physical Society at Montreal, Canada, June 19, 1947.

[1] J. W. Broxon, Phys. Rev. **70**, 494 (1946).

[2] J. W. Broxon, Phys. Rev. **37**, 1320 (1931). Figure 3, p. 1323, shows a longitudinal section of the chamber. The collecting electrode and the plug holding the cones have been modified, but the dimensions of the chamber are correctly designated here.

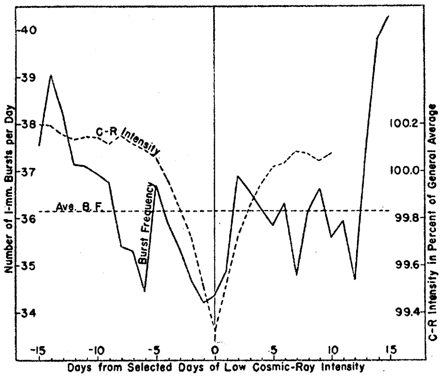

FIG. 2. Primary negative pulse in cosmic-ray intensity, together with corresponding pulse in frequency of 1-mm bursts.

over 14 cm at a zenith angle of about 42°, to a minimum of about 4 cm for horizontal rays. The somewhat non-uniform shielding afforded by the chamber walls and surrounding lead can perhaps be regarded as roughly equivalent to a lead shield of about 18-cm thickness. The chamber was further shielded by the building. Its location was in the basement near the foot of one of the outer stone walls whose thickness was 2.5 ft. at the bottom and which extended some 70 ft. above the chamber. It is difficult to estimate the shielding afforded by the building with its towers and numerous buttresses as well as concrete beams and floors and interior stone walls. Dr. Whaley has estimated that it was roughly equivalent in absorbing power to 39 cm of lead. With the exception of a very small solid angle subtended by a portion of a nearby sunken window, it would appear that the shielding afforded by the building would probably amount to some 15 cm of lead for any direction, and certainly much more than 40 cm for certain directions. In the present investigation, the same data were employed as in the preceding paper;[1] the number of small bursts per day during the period of observation (June, 1938, to November, 1939, inclusive) was not corrected for the two-minute grounding period each hour, and the nearest integral number was employed when corrections were applied because of lack of data for some of the 24 hours of the day. Also, no corrections were applied for variations of atmospheric pressure or other variables.

The indications of recurrence of variations in the frequency of occurrence of the small bursts are reminiscent of the recurrences of variations of the daily average ionization current in the same chamber during the same period of observation. Secondary pulses in the latter, after correction for bursts and for variations of barometric pressure, were found by the author[3] to occur at approximately 28-day intervals, and to extend at least as far as four such intervals before and after the corresponding primary pulses. Because the primary pulses in the daily average ionization current were also found[4] to have associated with them very definite inverse pulses in the terrestrial magnetic character and also in the total sunspot area, it was thought that there might likewise be found some such relation for the frequency of occurrence of the small bursts

First it was decided to investigate further the relation between the frequency of the small bursts and the (corrected) average ionization current. As mentioned formerly,[1] no clear relation was displayed among the four groups of 90 zero days each, which were selected as the 5 days in each of the 18 months during which the average ionization current was greatest or least or the small-burst frequency was greatest or least. As stated, "17 zero days selected for their large number of 1-mm bursts were identical with days selected on the basis of large average cosmic-ray ionization current, and 22 zero days selected for their small number of 1-mm bursts were identical with those selected for their small average current. On the other hand, 9 zero days selected for their large number of 1-mm bursts were identical with those selected on the basis of small average current, and 13 zero days selected for their small number of 1-mm bursts were identical with those selected for their large average current."

To test the relation further, the zero days selected on the basis of large or small average (corrected) C-R ionization current were employed for the burst-frequency data, just as was done in investigating the relation between the average C-R ionization current and either magnetic character or sunspot areas in earlier work.[4] Figure 1 shows the curve obtained for the frequency of the small bursts by Chree's method for the 18-month interval, with zero days selected on the basis of high average C-R ionization current,

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[3] J. W. Broxon, Phys. Rev. **59**, 773 (1941).
[4] J. W. Broxon, Phys. Rev. **62**, 508 (1942).

from day number -15 to $+15$. As in all the diagrams, the ordinates indicate the number of bursts per 24-hour day, not corrected for the 2-minute grounding period each hour. The dotted curve represents the corresponding average C-R ionization current for the same zero days, expressed in percent of its over-all mean. This is the same dotted curve designated in Figs. 1 and 6 of reference 4 as representing the primary pulse in the cosmic-ray intensity, and extends only to $n=10$ for positive day numbers. While the frequency of the small bursts is seen to be above average in the neighborhood of the zero days selected on the basis of their large average ionization currents, there are peaks on either side of the zero, and the shape of the curve does not correspond at all well to the form of the curve representing the C-R intensity or average ionization current. A striking feature of the burst-frequency curve is the magnitude of the departures from the average which extend to some 9 percent in comparison with the primary positive peak in the C-R intensity which departs less than 0.7 percent from the average.

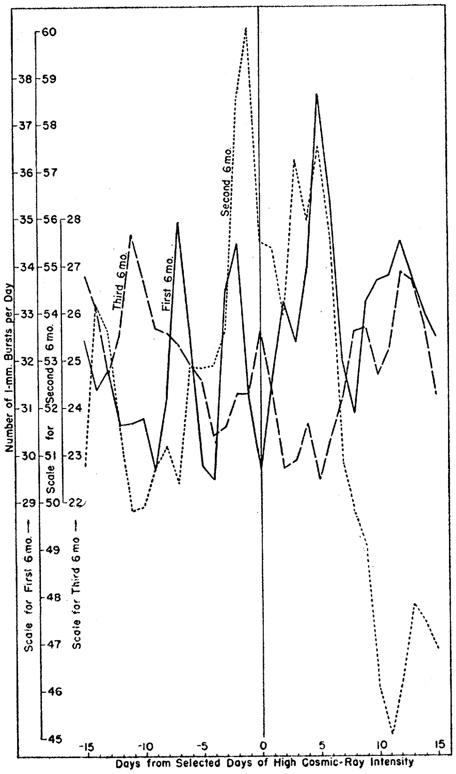

FIG. 3. These curves represent variations of frequency of 1-mm bursts in the neighborhood of the primary positive pulses in C-R intensity for each of the three successive six-month intervals of the period of investigation. The corresponding pulses in C-R intensity are not shown; their peaks would fall on day number zero, of course, as in Fig. 1.

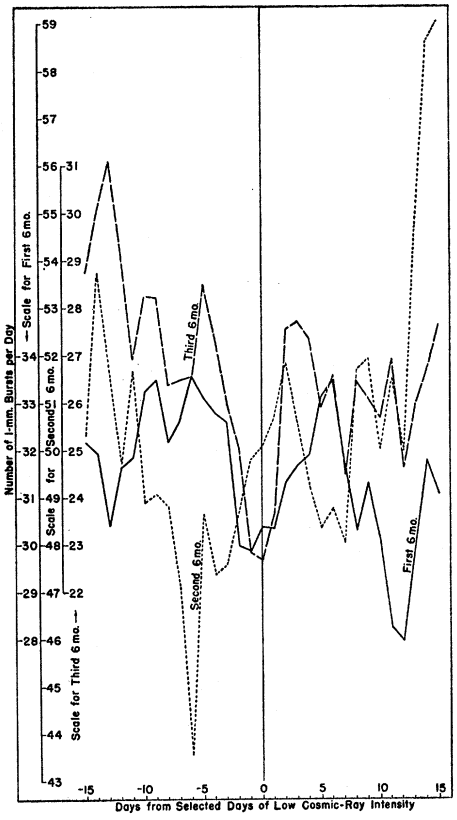

FIG. 4. These curves represent variations of frequency of 1-mm bursts in the neighborhood of the primary negative pulses in C-R intensity (not shown) for the successive 6-month intervals.

Figure 2 shows the curve obtained for the frequency of the small bursts with zero days selected on the basis of small C-R intensity (or average ionization current) for the 18-month interval. The dotted curve here represents the primary negative pulse in the C-R intensity, and is identical with the dotted curve of Figs. 2 and 7 of reference 4. Here there is a considerable dip in the burst-frequency curve in the immediate neighborhood of the selected days of low C-R intensity, but the curve fluctuates about the average a little further from the zero days, and there are other dips nearly as low. The high values a couple of weeks before and after the zero day number are rather striking. Altogether, there

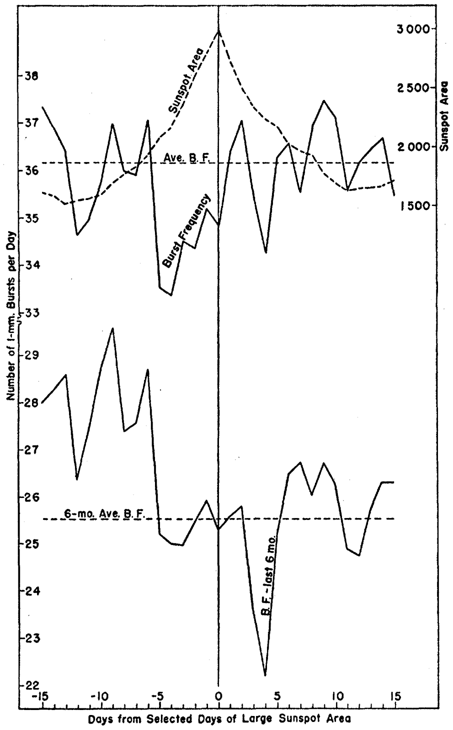

FIG. 5. Primary positive pulse in sunspot area, together with corresponding pulse in frequency of 1-mm bursts for the 18 months, are shown by upper curves. The lower curve represents the variation of burst frequency with respect to zero days of large sunspot area selected only from the last 6 months.

does not seem to be a very close correspondence between the two curves.

Because of the irregularities of the burst-frequency curves associated with the positive and negative primary pulses in the C-R intensity for the 18-month interval, and because it was observed that the frequency of occurrence of the small bursts was considerably greater during the winter and spring months than during the summer and fall months, it was decided to form corresponding separate diagrams for zero days restricted to 6-month intervals. These are shown in Figs. 3 and 4. The curves for the first 6 months and for the third 6 months were obtained with zero days selected from the months June–November, inclusive, of 1938 and 1939, respectively, while those for the second 6 months were obtained with zero days selected from the intervening months, December–May. The dependence of the frequency of occurrence of the small bursts upon the season is roughly shown by the scales employed for the individual curves of these diagrams. For Fig. 3 the zero days are those selected on the basis of high C-R intensity (or average ionization current), while for Fig. 4 the zero days are those of low C-R intensity.

To the writer it appears that about all that is provided by Figs. 3 and 4 is further confirmation of the indications of Figs. 1 and 2 that there is not a very intimate relation between the frequency of occurrence of the small bursts and the intensity of the hard component of the cosmic radiation as represented by the average ionization current. It should be borne in mind, of course, that appreciably more random fluctuations should be expected for a 6-month than for an 18-month interval, because of the smaller number of data involved. Rather more of a direct relation appears in the curves for the winter and spring months than in those for the summer and fall months which seem to represent quite random fluctuations. Because of the much larger number of bursts during the second 6-month interval, this interval has a very considerable influence in determining the shapes of the curves of Figs. 1 and 2 for the 18-month interval.

To investigate the relation between burst frequency and sunspot area, zero days were chosen

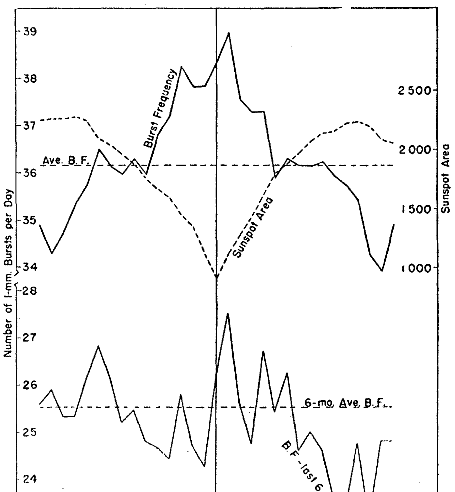

FIG. 6. Primary negative pulse in sunspot area, together with corresponding pulse in frequency of 1-mm bursts for the 18 months, are shown by upper curves. The lower curve shows variations of burst frequency with zero days of small sunspot area selected only from the last 6 months.

on the basis of sunspot area. This differed from the procedure in reference 4 for establishing the relation between C-R intensity and either sunspot area or magnetic character, for there the zero days were selected on the basis of C-R intensity. For Fig. 5 the zero days were the five of greatest sunspot area in each month. The sunspot data are the same as employed in reference 4. The sunspot-area values used represent the sum of the areas of all visible sunspots, corrected for foreshortening, in terms of one-millionth of the sun's visible hemisphere as unit. The upper burst-frequency curve was obtained with zero days for all eighteen months, as was the dotted curve representing the primary positive pulse in sunspot area. While the average total sunspot area during the 18 months, 1889.3 units, is not designated in Figs. 5 and 6, this is not very much greater than the value corresponding to the horizontal line representing the average burst frequency. Although the burst-frequency curve is quite irregular and represents quite random fluctuations about the average over most of the range (−15 to +15) of day numbers investigated, there is a rather especially deep and broad dip in the curve extending nearly 8 percent below the average, with its lowest point at 4 days before the zero days of large sunspot area. Unfortunately, we have no mathematical criteria to assist in deciding when such a deviation is "significant." The author is inclined toward the view that the curve does provide some indication of an inverse relation between variations in burst frequency and sunspot area. Because of the much lower frequency of occurrence of the bursts during the summer and fall months, a separate curve with zero days from only the last 6 months has been included in this and some subsequent diagrams. In Fig. 5 the burst-frequency curve for the last 6 months also shows a decided dip, narrower than in the 18-month curve and with its tip at $n=+4$, with quite high values in the region $n=-15$ to -6.

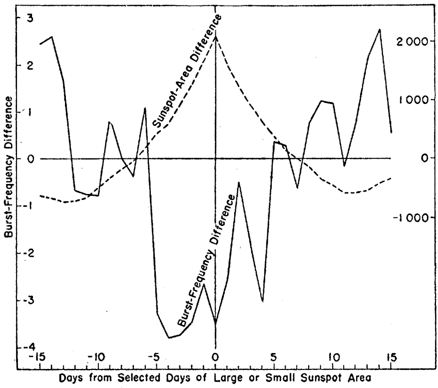

FIG. 7. Primary "difference" pulse in sunspot area, together with corresponding difference pulse for burst frequency for the 18 months. These curves were obtained by subtracting ordinates of the upper curves of Fig. 6 from the corresponding ordinates of Fig. 5.

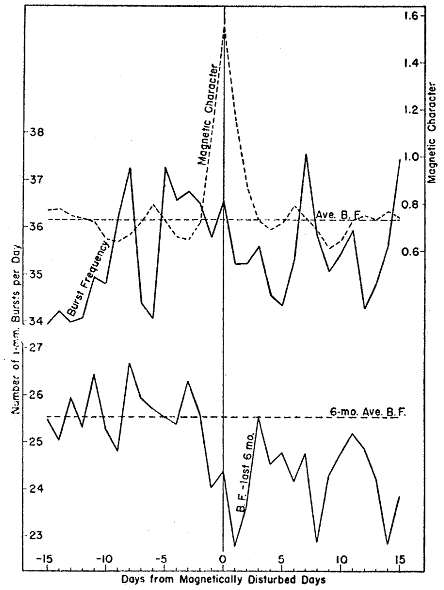

FIG. 8. Primary positive pulse in magnetic character, together with corresponding fluctuations in frequency of 1-mm bursts for the 18 months, shown by upper curves. Lower curve represents variation of burst frequency relative to magnetically disturbed days selected only from the last 6 months.

The curves of Fig. 6 were constructed by a procedure precisely analogous to that followed in the case of Fig. 5, except that here the zero days were the five of least total sunspot area in each month. The burst-frequency curve for the 18 months here shows a very definite pulse in phase opposition to the negative primary pulse in sunspot area. It is above the average for an interval of some 10 days, and well centered relative to the zero days of least sunspot area, with its highest peak (representing a deviation a little less than 8 percent from the average) at day number 1. The burst frequency is also definitely below average two weeks before and after the zero days. This seems to constitute the best indication of an interrelation between burst frequency and another variable which is provided by this analysis. This indication of an inverse relation between burst frequency and sunspot area appears quite as clear-cut as that provided by the comparable curves of Figs. 6 and 7 of reference 4 which show an inverse relation between sunspot area and C-R intensity as measured by the average ion current. The curve for the last 6 months, however, cannot be considered to provide further substantiation; it scarcely indicates any relation between the variables.

Figure 7 shows "difference" curves obtained from the 18-month curves of Figs. 5 and 6 in the usual manner, ordinates being obtained by subtracting the ordinates in Fig. 6 from the corresponding ordinates in Fig. 5. The burst-frequency difference curve of Fig. 7 also displays a definite pulse in burst frequency in approximate phase opposition to the primary pulse in the sunspot-area difference curve.

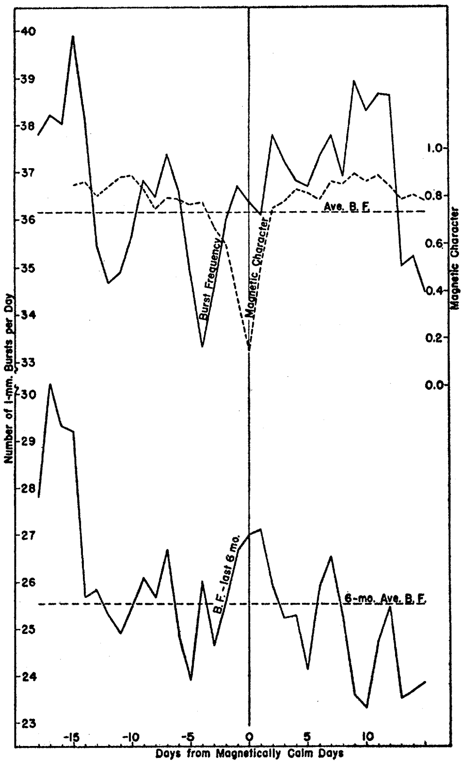

FIG. 9. Primary negative pulse in magnetic character, together with corresponding fluctuations in frequency of 1-mm bursts for the 18 months, are shown by upper curves. Lower curve represents variation of burst frequency relative to magnetically calm days selected only from the last 6 months.

Figures 8, 9, and 10 represent the results of an investigation of a possible relation of the burst frequency to magnetic character, carried out step by step in accordance with the procedure employed in obtaining Figs. 5, 6, and 7, respectively. In this case, the world-wide magnetic character numbers employed in reference 4 were used in place of sunspot areas, and the zero days were the five magnetically disturbed or calm days in each month selected by van Dijk. The actual character numbers are designated on the scales of ordinates. While the average magnetic character number for the 18 months is not designated in Figs. 8 and 9, its value, 0.753, is not far above that corresponding to the line representing average burst frequency.

The upper burst-frequency curve of Fig. 8, obtained with zero days for the entire 18 months, displays quite large and apparently random fluctuations with no evidence of a relation to the primary positive pulse in the magnetic character, at least within 15 days preceding or following the magnetically disturbed days. The lower curve of Fig. 8, obtained with zero days from only the last 6 months, might conceivably be considered to provide a weak indication of an inverse relation in view of the dip at day number 1. Since the dips at day numbers 8 and 14 are quite comparable to this, however, such an indication must be regarded as quite unconvincing.

In the upper, 18-month, burst-frequency curve of Fig. 9, some evidence of a direct relation between burst frequency and magnetic character seems to be provided by the sharp dip centered at 4 days preceding the magnetically calm days and descending 7 percent below the average. The curve is quite irregular, however, and the dips at day numbers −12 and +15 make the indication less convincing. The curve for the last 6 months appears to indicate only random fluctuations. It might be considered to afford the barest hint of an inverse relation.

The burst-frequency "difference" curve of Fig. 10, obtained from the 18-month curves of Figs. 8 and 9, appears to provide some indication of a direct relation between the burst frequency and magnetic character, but the indication is weakened by the irregularity of the curve, particularly the dip at day numbers −6 and −7, and the high value at +15. Such indication as exists seems to be due almost entirely to the burst-frequency curve of Fig. 9, associated with magnetically calm days.

In summarizing the results of this analysis, it may be remarked that while it indicates that the frequency of occurrence of the 1-mm bursts is likely to be above or below average when the cosmic-ray intensity (as measured by the corrected average ionization current) is particularly high or low, respectively, the forms of the burst-frequency curves associated with the primary pulses in C-R intensity indicate that there is not a very intimate relation between these variables.

Good evidence is found for an inverse relation between the burst frequency and sunspot area. This is more clear-cut in the case of sunspot minima than in the case of sunspot maxima. This inverse relation appears to be generally comparable to that found earlier to exist between C-R intensity and sunspot area, though the curves obtained here are somewhat less regular than those of the earlier paper, and do not show any indication of the phase lag found there. There is one very striking difference in the magnitudes involved. The pulses in small-burst frequency associated with primary pulses in sunspot area extend to nearly 8 percent deviation from the average, while the primary pulses in the mean corrected ionization current represent[4] only 0.5 to 0.7 percent deviation.

There is very little evidence of a relation between the frequency of the small bursts and terrestrial magnetic character. Lack of correlation with magnetic character can scarcely be regarded as conclusive evidence of a lack of dependence upon the terrestrial magnetic field, of course, in view of the extraordinary definition of magnetic "character." It is rather striking, however, that the earlier work indicated a very clear-cut inverse relation between the C-R intensity and magnetic character. Such relation as is indicated in the present instance appears to be rather of opposite character.

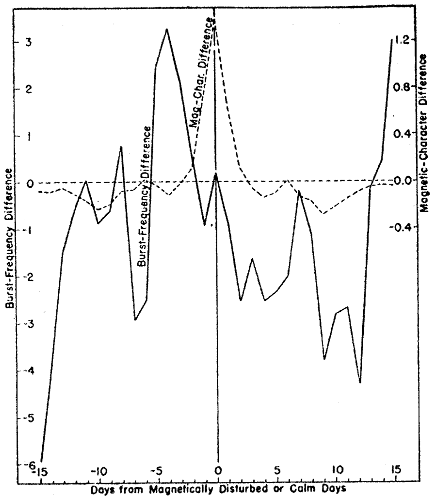

FIG. 10. Primary "difference" pulse in magnetic character, together with corresponding differences in burst frequency for the 18 months. These curves were obtained by subtracting ordinates of the upper curves of Fig. 9 from the corresponding ordinates of Fig. 8.

Because of the heavy shielding employed, it is apparent that both the average ionization current and the bursts observed in the chamber must have been caused by penetrating radiations. If both were caused by the same radiation, then one might suppose that both should display corresponding variations in relation to variations in magnetic character as well as in sunspot areas, and also that their variations should display a much closer mutual relationship than is apparent in Figs. 1 and 2, just as they both display recurrences of variations at the comparable intervals of 27 or 28 days,[1, 3] variations amounting to about 0.2 percent in the current and 3 or 4 percent in the burst frequency. It occurs to one that the situation might be explicable by virtue of the fact that the daily average ionization currents were corrected for variations in barometric pressure (as well as for bursts) while no such correction was applied in the case of the burst frequencies. If the burst frequency does depend to a considerable extent upon barometric pressure (it will be shown later that it does), then it is perhaps remarkable that without correction there are still inverse pulses in the burst frequency related to the primary pulses in the sunspot area as shown in Figs. 5, 6, and 7. At present it appears likely that the ionization current (after correction for bursts) and the small bursts may be due in considerable part to two different types of penetrating radiation. If, for instance, the average ionization current in the chamber were brought about largely through the agency of mesotrons and if the small bursts were, to a considerable extent,

TABLE I. Correlation between burst frequency and barometric pressure.

Month	Bar. coeff. of B. F. in percent per mm Hg	Corr. coeff.
Aug. 1938	2.4	0.18
Nov. 1938	−1.1	0.30
Jan. 1939	−4.0	0.73*
Feb. 1939	−2.4	0.57
Mar. 1939	−3.5	0.60
Apr. 1939	−1.6	0.23
Apr. 1939	−3.3	0.48**
June 1939	−2.7	0.28
Aug. 1939	−2.1	0.18

* Last day omitted.
** Correlation of B. F. with Bar. Press. for *preceding* day.

the result of the action of neutrons,[5] then, if these are produced by different processes and their respective intensities do not bear precisely similar relations to other variables or for any reason do not display closely similar fluctuations in time, the relations displayed in this investigation and those leading up to it might be capable of explanation on this basis.

The small-burst frequencies were employed in this investigation without any correction for possible barometric or other effects, because the uncorrected frequencies had displayed[1] the 27-day recurrences. Because the analysis provided indications that the small bursts and the ionization after correction for bursts may be produced through the agency of two different types of radiations, while permitting the supposition that some of the results might be explicable in terms of a barometric effect on the burst frequency, it was decided to carry out a preliminary investigation of such an effect. Consequently, a least-squares' analysis of the relation between the number of 1-mm bursts per day and the average barometric pressure for the day was carried out for 8 of the 18 months. The particular months investigated were selected partly because of distribution in season, and partly because of the range of variation of barometric pressure during the month. The results are collected in Table I.

The second column in Table I gives the barometric coefficient for the frequency of the small bursts in percent of the average for the month (designated in the first column) per mm Hg variation in the barometric pressure. The third column gives the correlation coefficient. Data for the last day of January were omitted because the correlation coefficient was thereby nearly doubled. For April, values obtained by associating the number of 1-mm bursts for each day with the mean barometric pressure for the preceding day are also included.

Table I shows that for 7 of the 8 months investigated, large negative barometric coefficients, of the order of 1 to 4 percent decrease in burst frequency per mm Hg increase in barometric pressure, were indicated. The single positive coefficient obtained was for August, 1938. For this, as for August, 1939, the correlation coefficient was so small as to render the correlation quite meaningless. It is quite common to consider that a correlation is not really significant or reliable unless the correlation coefficient is three times as great as its mean error. On this basis, only January, February, and March, of the months investigated, display reliable correlations. The data for April also satisfy this criterion for reliability if the number of bursts for each day is associated with the mean barometric pressure for the *preceding* day rather than for the day on which the bursts occurred. This might conceivably be due to a lag in the representation of some higher atmospheric conditions by barometric pressure at the earth's surface at this season of the year. Because casual observation of the data did not indicate that such an improved correlation would result from a corresponding treatment of data for the other months, this was not attempted. The extreme lack of significance of the coefficients obtained for the two August months is made apparent by the fact that, for both of these, the mean error in the correlation coefficient was about equal to the correlation coefficient itself. In fact, if data for August 29 are omitted from August, 1938, the barometric coefficient for that month is reduced from 2.4 to 1.1, and the correlation coefficient from 0.18 to 0.09. For November and June the correlation coefficients are about twice their mean errors.

It will be noted that the most reliable barometric coefficients of burst frequency all have large negative values. These are all for months with higher than average burst frequency, less than average barometric pressure, fairly large

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[5] C. F. v. Weizsäcker, in Part 7 of *Cosmic Radiation* (Edited by W. Heisenberg; translation by T. H. Johnson; Dover Publications, New York, 1946), ascribes cosmic-ray bursts under thick shields to mesons of spin zero.

range of variation of barometric pressure, and certainly in the case of January and February, low temperature. The August months had higher average barometric pressures than the average for the year, higher temperatures, and considerably lower than average small-burst frequency.

To obtain a single value somewhat representative of the "significant" barometric coefficients, an average has been obtained by weighting the values for January, February, and March, and the second (delayed) value for April according to their respective correlation coefficients. This procedure yields -3.4 percent per mm Hg. This is definitely of a higher order of magnitude than the barometric coefficient for the corrected ionization current in the same shielded chamber. The mean value of the latter for the 18 months was -0.145 percent per mm Hg.

It is seen that the barometric coefficients, as well as the Chree analysis, indicate that the small bursts and the corrected ionization current in the heavily shielded chamber are produced through the agency of different types of radiation. The observed dependence of the burst frequency upon barometric pressure, at least during a certain season, makes it seem desirable to repeat the Chree analysis after applying barometric corrections to the burst frequency. Their very different barometric coefficients, however, make it seem very unlikely that such a procedure would indicate any better correlation between burst frequency and ionization current in the shielded chamber. The very large barometric coefficient for the burst frequency indicates a much greater likelihood of a correlation between the frequency of the small bursts and a soft component[6] of the cosmic radiation. Such a soft component, to account for the bursts, must produce a radiation capable of penetrating the thick shield and actuating the bursts while contributing little to the average ionization. It should be borne in mind that with air in the chamber at 160 atmospheres, it would not be possible to collect efficiently the ions of a burst if these ions were finally produced by the action of any short-range particles producing high ion density.

The large barometric coefficient found for the small bursts in this investigation corresponds strikingly to the much earlier observations of Steinke, Gastell, and Nie.[7] Employing a large chamber (500 liters) containing CO_2 at rather low pressure (2 kg CO_2; hence, about 2 atmospheres) shielded by 10 cm of lead, they observed a barometric coefficient of about -5 percent per mm Hg. For the ionization current they found a barometric coefficient of only 0.2 percent per mm Hg. Both these coefficients correspond closely to the values obtained here. They did not observe a barometric effect for large bursts, but only for small ones ($1-7\times10^6$ E. Q., occurring at the rate of one in two hours or oftener). Moreover, the effect decreased with increased shielding, being no longer observable with 30 cm of iron. They attributed the latter situation to an increased number of bursts being caused by secondary radiation from the shield and consequently not susceptible to variations resulting from changes in barometric pressure. They considered the very large barometric coefficient for the small bursts obtained with the 10-cm lead shield to indicate their association with an extremely soft component of the cosmic radiation.

Montgomery and Montgomery[8] also observed a negative barometric coefficient for cosmic-ray bursts. Employing a 50-liter Dowmetal chamber containing nitrogen at 14.5 atmospheres and shielded by about 4 cm of lead on top, and measuring bursts greater than 1.6×10^6 ions, they obtained an estimated barometric coefficient of -0.5 percent per mm Hg at sea level, and about -7 at 4300 meters (where the burst frequency was 90 to 150 per hour), though variation with altitude there indicated a coefficient less than half as great.

In summarizing the evidence for the supposition that the small bursts and the (corrected) ionization in the shielded chamber are produced through the agency of different types of radiation, we have first the lack of close correlation between variations of these as indicated by Figs.

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[6] W. Kolhörster, Physik. Zeits. **40**, 107 (1939), found 27-day fluctuations in cosmic-ray intensity out of phase with sunspot relative numbers, etc. He used a dual telescope arrangement measuring the vertical intensity. While there does not appear to be a definite statement regarding shielding, it seems likely that very little shielding was employed.

[7] E. G. Steinke, A. Gastell, and H. Nie, Naturwiss. **21**, 898 (1933).

[8] C. G. Montgomery and D. D. Montgomery, Phys. Rev. **47**, 429 (1935).

1, 2, 3, and 4. Also, while both burst frequency and corrected ionization current display recurrences of variations at intervals of 27 or 28 days, primary pulses in the former (expressed in percent) are about 60 times as great as in the latter, and secondary pulses are about 20 times as great. Also, while both display variations in general phase opposition to those in sunspot area, the pulses in burst frequency (expressed in percent) in this instance are some 11 to 16 times as great as the primary pulses in the ionization current. The corrected ionization current displays a clear-cut relation to magnetic character not displayed by the raw burst-frequency data; it remains to be seen whether correction for barometric variations would bring out a closer relation between burst frequency and magnetic disturbances. Finally, while the barometric coefficient for the frequency of the small bursts is of the same sign as that for the corrected ionization current, it is some 20 times as great, at least for the season when the dependence upon barometric pressure is clearly evident. The indication here provided that the bursts are associated with a soft component calls to mind the fact that Korff[9] found the rate of production of neutrons to be associated with the soft component.

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[9] S. A. Korff, Phys. Rev. 59, 949 (1941).

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Gamma-Rays from the Alpha-Particle Bombardment of Na, Mg, Al, Si, P, S

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Na, Mg, Al, Si, P, S targets have been bombarded by 7.2-Mev helium ions. The emission of gamma-radiation has been observed. Lead absorption coefficients were obtained in all cases. The values lie close to the minimum of the lead absorption curve. In the case of Al, absorption in copper has been measured and, in addition, absorption of Compton recoil electrons by aluminum has been measured by a coincidence method. The results show that a gamma-ray of energy 3.5±0.3 Mev is present. This agrees with a transition from the Q_2 to Q_0 state observed in the $Al^{27}(\alpha p)Si^{30}$ reaction. Unequivocal energy assignments cannot be made for the remaining reactions. However, lead absorption experiments indicate the following probable values: S, 1.6±0.3 Mev; Mg, 3.2±0.6 Mev; Na, 2.3±0.3 Mev. The values for elements Si and P cannot be assigned until it is clear whether the absorption is above or below the minimum. Lead absorption coefficients are given. Since the gamma-ray energies are generally higher than the difference between energy levels obtained from other information, it is likely that in these cases direct transitions are preferred to cascade.

1. INTRODUCTION

In the region between sodium and chlorine there has been a considerable amount of experimental work on the nuclear energy levels as revealed by the formation of groups of particles in transmutations[1] or of inelastically scattered protons.[2] Relatively little recent work has been done on the direct observation of radiation due to transitions between levels of excitation produced in the bombardment process. Savel,[3] bombarding with polonium alpha-particles, has observed the presence of gamma-radiation from fluorine, sodium, magnesium, and aluminum, and measured the absorption coefficients in lead. Speh[4] has shown that the energy of the radiation from fluorine bombarded by polonium alpha-

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[1] For example, C. J. Brasefield and E. Pollard, Phys. Rev. 50, 296, 890 (1936); A. N. May and R. Vaidyanathan, Proc. Roy. Soc. A155, 519 (1936); O. Haxel, Zeits. f. Physik 90, 373 (1934), and Zeits. f. Tech. Physik 11, 410 (1935), H. L. Schultz, W. L. Davidson, Jr., and L. H. Ott, Phys. Rev. 58, 1043 (1940).

[2] R. H. Dicke and J. Marshall, Phys. Rev. 63, 86 (1943).

[3] P. Savel, Ann. de physique 4, 88 (1935).

[4] K. D. Speh, Phys. Rev. 50, 689 (1936).