Recordinds of Cosmic Radiation

By K. G. MALMFORS
The Royal Institute of Technology, Stockholm

(Manuscript received 22 April 1949).

Abstract:

The main purpose of the registrations reported here has been to study the diurnal variations of C. R. and especially to investigate how the amplitude and the phase of the variation depend on the direction of incidence. Since statistical fluctuations will dominate over the significant ones unless a sufficiently large number of coincidences is counted, it has been necessary to use an apparatus with a high counting speed. C. R. has been recorded continuously in Stockholm (magn. lat. 58°) since 1. 10. 1947 by means of large counters in coincidence circuit. Recordings have been made in three different directions simultaneously, and the total number of particles counted amounts to 10^9. The material has been analyzed with respect to diurnal variation. This analysis definitely proves that the variation is not the same in different directions. A term called C. R. activity has been introduced for the purpose of classifying the registrations according to the magnitude of the variation for each day. An analysis shows that large activity is very often observed during consecutive days.

Introduction

The intensity of C. R. recorded at the earth's surface undergoes only small variations. The largest ones are due to atmospheric influences. Since the absorption of C. R. in the atmosphere depends on the amount of matter traversed the intensity of the radiation is closely correlated to changes of barometric pressure. The coefficient can be accurately determined and consequently it is easy to make a correction for such variations. On the other hand the intensity shows some correlation with the air mass distribution as was first pointed out by BLACKETT (1938), who interpreted this temperature effect as being due to the fact that, when the atmospheric temperature is high, the mesons originate from a higher level, which leads to a greater probability for their decaying before reaching the earth's surface. The effect has recently been studied by DUPERIER (1945, 1948), who correlated the intensity of C. R. with the height of the 100-millibar surface determined from balloon sondations. A correlation coefficient as high as 0.67 was obtained and the dependance was determined at 5.4 %/km.

Cosmic ray intensity is very intimately associated with magnetic storms and, even though this connexion shows many complex features, it seems probable that investigations following this line will give essential knowledge of the nature of the magnetic storms. The analysis of the present registrations in this respect will be reserved for a later publication.

The diurnal variations of C. R. with respect to solar and siderial time have been studied by many investigators. Recent results concerning variation with solar time show good agreement and indicate that the intensity is some few tenths of a percent higher in the afternoon than in the morning. On the other hand, the existence of some variation with siderial time has not been established with any certainty. Results indicating such a variation may probably be interpreted as being due to seasonal changes of the variation with solar time.

Apparatus

The apparatus described here is mainly an enlarged copy of an apparatus used for continuous registrations during the period 1939—1943 (Alfvén and Malmfors 1943).

The counters used are made of brass tubes (diam. 15 cm, length 50 cm) closed at the ends by plane brass plates. The axial wire (Wo, ∅ = 0.2 mm) is suspended by using glass metal seals. Filled with carefully dried argon-alcohol mixture (10 mm C_2H_5OH, 35 mm Ar) the counters operate satisfactorily at about 1 400 volts. The length of the plateau is usually about 200 volts. The high voltage for the tubes is supplied from dry batteries in order to ensure the highest degree of constancy.

Ten tubes arranged as shown in Fig. 1 make it possible to record the intensity in twelve coincidence sets simultaneously, (4 channels recording the intensity from the zenith, 4 channels that from a cone inclined to the north and 4 channels the intensity from the south). The number of coincidences in each of these channels is recorded separately by an ordinary coincidence amplifier with Rossi circuit, scale-of-four and a mechanical recorder fed by a thyratron.

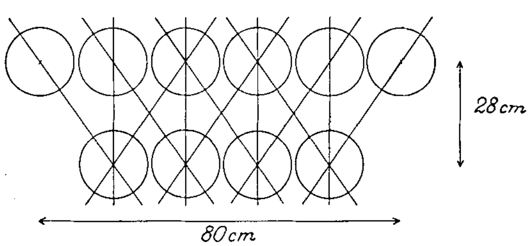

Fig. 1. Arrangement of the counters.

The anode- and grid voltages and the filament currents of the amplifiers are stabilized in such a manner that no appreciable variations can arise from fluctuations of the main.

By counting the intensity from each direction in four independent channels valuable control is obtained. If one of the counters or one of the amplifiers does not operate satisfactorily this is easily detected by comparing the four channels. In such a case three of them will show good parallelism while the fourth varies irregularly and can be repaired without interrupting the counting in the three undisturbed channels.

The recorders are photographed once every hour by means of a signal clock and a relay system.

The apparatus is placed in a little cottage a hundred meters away from other buildings. The temperature in the room is kept constant to within some tenths of a degree. On days when temperature variations exceeded 0.5° C the registrations have not been subjected to analysis.

Representation of data

Tab. I, which is a reproduction of the photographic recordings, shows how the counting capacity of the apparatus 115 000 coincidences/hour, is distributed between the different channels. (It should be noted that, owing to the scale-of-four, the real number of coincidences is four times as great as that derived from the photographs.) The results given here comprise registrations during the time 1/10 1947—8/1 1949, the total number of coincidences amounting to about 10^9. The first step in the treatment of the material has been to plot the 24-hour values of each channel, in order to control the counters and the ampli-

Table I

3/7 1948		Z				N				S			
01^{00}	8774	6662	6235	5151	4000	1472	0602	6556	8793	7893	0034	6933	6213
02^{00}	8775	9636	9296	8166	7061	3382	2447	8508	1013	9721	1831	8773	8151
03^{00}	8776	2581	2458	1223	0101	5289	4375	0465	3201	1567	3635	0604	0126
04^{00}	8777	5527	5528	4296	3128	7189	6272	2395	5351	3410	5458	2434	2099

Table II

3/7 1948	Z	N	S	Bar.	Z	N	S	Z	N	S
0^{00}	24167	15797	15010	758.6	24089	15746	14962	2.5	1.7	3.2
2^{00}	24315	15907	14859	758.6	24237	15856	14811	3.1	2.4	2.2
4^{00}	24242	15863	14904	758.6	24164	15812	14856	2.8	2.1	2.5

fiers. If one of the channels has happened to vary irregularly, it has been excluded. The remaining channels have been summed up and 2-hour values have been calculated. The first three columns of Tab. II contain values obtained in this way. Barometric data have been kindly supplied by The Meteorological Station, Stockholm, and during the whole

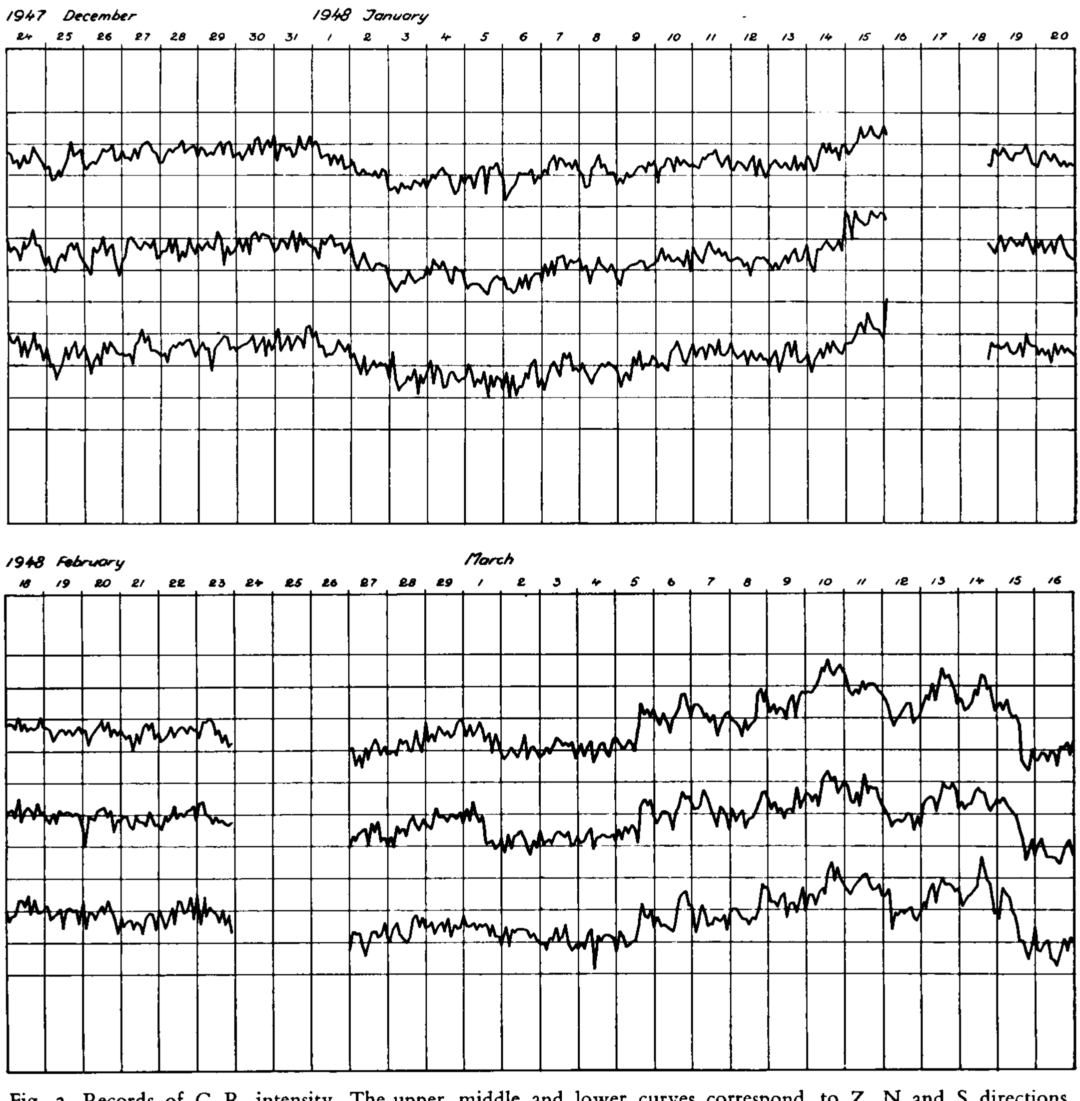

Fig. 2. Records of C. R. intensity. The upper, middle and lower curves correspond to Z, N and S directions respectively. The distance between the lines is 2 %.

Table III

		Disturbed days	Quiet days
1947	Oct.	1, 2, 4, 5	13, 18, 20, 22, 23 24, 29, 30
	Nov.	25, 26	7, 16, 18, 19, 20, 21, 23, 28
	Dec.	23, 24, 25	2, 3, 7, 8, 11, 12, 13, 20, 21, 30
1948	Jan.	21, 29	2, 3, 10, 11, 12, 13, 19, 20, 24, 25, 26, 27, 30
	Febr.	1, 23	6, 7, 9, 10, 14, 17, 19, 29
	March	5, 6, 8, 10, 11, 13, 14, 15, 21	4, 18
	April	4, 8, 15	1, 13, 30
	May	8, 13, 17, 22, 30	1, 5, 7, 9, 10, 18, 19, 20, 21, 28, 31
	June	7, 12	15, 16, 18, 30
	July	29, 30, 31	1, 13, 17, 21, 26
	Aug.	1, 6, 7, 8, 10, 13, 14, 20, 22	23, 25
	Sept.	9, 11, 15, 19, 20, 21, 25, 30	3, 4, 5
	Oct.	1, 18, 19, 22, 23	2, 3, 8, 12, 17
	Nov.	3, 6, 10, 11, 27	22, 24
	Dec.	5, 9, 10, 13, 20, 24 25, 26, 31	27
1949	Jan.	1	4

series of registrations the barometric coefficient — 0.23 %/mm Hg has been used. No correction has been applied with regard to the atmospheric temperature effect. After reduction to standard pressure (760 mm Hg) the material takes the form shown in the following three columns in Tab. II. Owing to the fact that one or more of the channels have sometimes had to be excluded, the corrected 2-hour values have been represented (in the last three columns) by the percentage deviation from a mean value. From the points of change which have always been made to occur at midnight, new mean values have been calculated. This has been done in such a way that the mean values of the curves for the preceding and the following day change in the same proportion as the mean values of the continuating channels.

An analysis of the material with respect to atmospheric influences will be published by Dr. LINDHOLM.

In Fig. 2 some parts of the registration series have been reproduced.[1] The upper, middle and lower curves correspond respectively to the Z, N, and S directions. The distance between the horizontal lines is 2 %. The period 10/3—16/3 1948 is one of large magnetic activity including a severe magnetic storm beginning on March 15. Since this representation of the data has been chosen for the analysis of short time variations, such channels have also been included which slowly and regularly decrease with time, which sometimes has been the case. No great importance should therefore be attached to apparent variations ranging over periods as long as one month or more. The long time variations are more accurately obtained by selecting only such channels as give perfectly parallel curves.

[1] The author will be pleased to send copies of the whole registration series to those interested.

The diurnal variation

A systematic diurnal variation can only occasionally be distinguished from the statistical fluctuations when studying the curves of Fig. 2. Significant results can only be obtained by calculating a mean variation covering several days. Each point in the harmonic dial diagrams of Fig. 3 has been obtained by summing up the results of six consecutive days. The mean values are represented by the square points. Fig. 4 shows curves obtained from registrations during intervals of 100 consecutive days. The similarity of the curves confirms the reproducibility of the variation. From any representation of the data as given above it is obvious that *the variation is not the same when measured in*

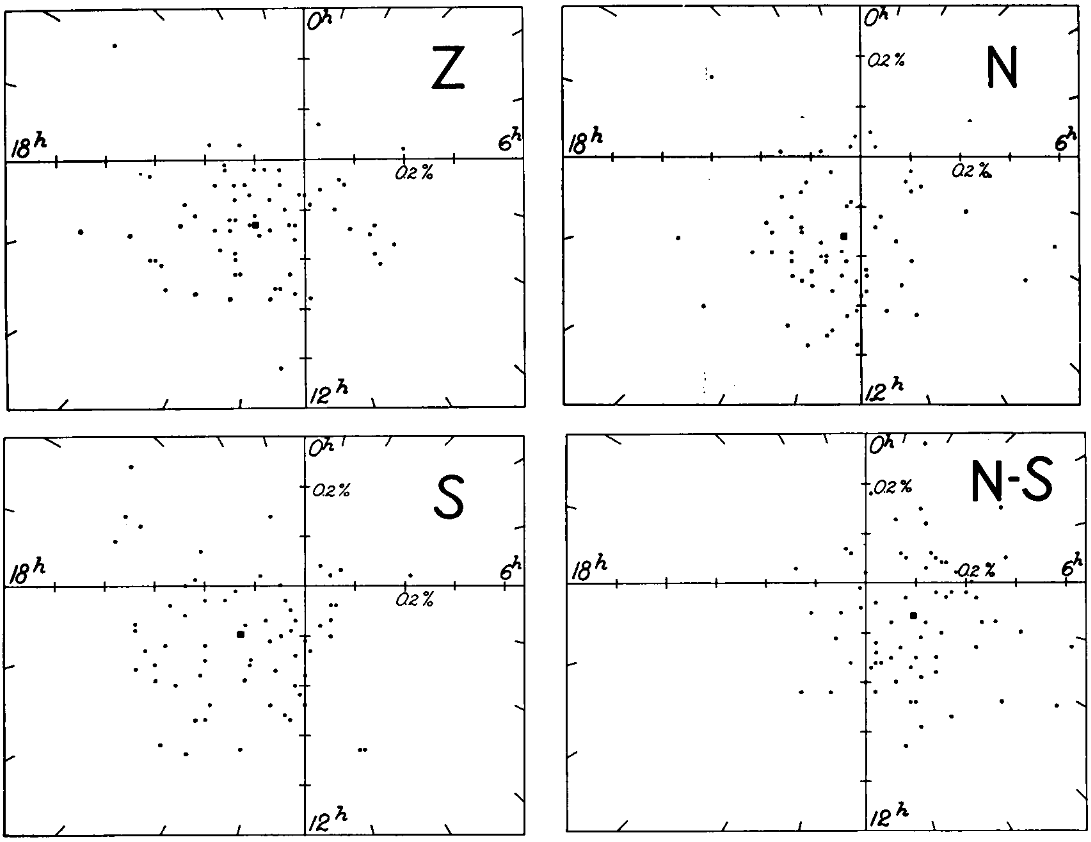

Fig. 3. Harmonic dial diagrams of diurnal variation. Each point corresponds to a period of 6 days. The square points represent mean values.

different directions. The curves for the difference, *N* minus *S*, have about the same amplitude as the individual curves. Similar results have been obtained from earlier registrations by KOLHÖRSTER (1941) and by ALFVÉN and MALMFORS (1943).

The harmonic diagrams of Fig. 3 show that *the dispersion of the points for N—S is less than that for the original directions*, a fact which may indicate that the phase difference between the curves for *N* and *S* is due to different deflection angles in the earth's magnetic field.

An analysis based upon the harmonic coefficients, calculated for each day, shows that the amplitude of the variation is not distributed at random. On several occasions large amplitues occur during consecutive days, as is also illustrated in Fig. 2. During the period 24—27/12 1947 a distinct variation, lasting for some days, is measured in all three directions.

Since this effect will probably be of importance for the interpretation of the variations, the term "Activity of Cosmic Radiation» has been introduced, referring to the magnitude of the variation during individual days. Analogous with the procedure adopted for the treatment of magnetic observations, the material has been classified into quiet and disturbed days. In the case of the present registrations this has been effected in the following way. To the amplitude intervals 0—0.25, 0.25—0.40, 0.40—0.60, >0.60 % have been assigned the indices 0, 1, 2, 3 respectively. In this way the C. R. activity for each day is given by a total index which is the sum of those for the Z, N and S directions. For 72 days which are called disturbed days this total index is 6 or more. 107 days have the

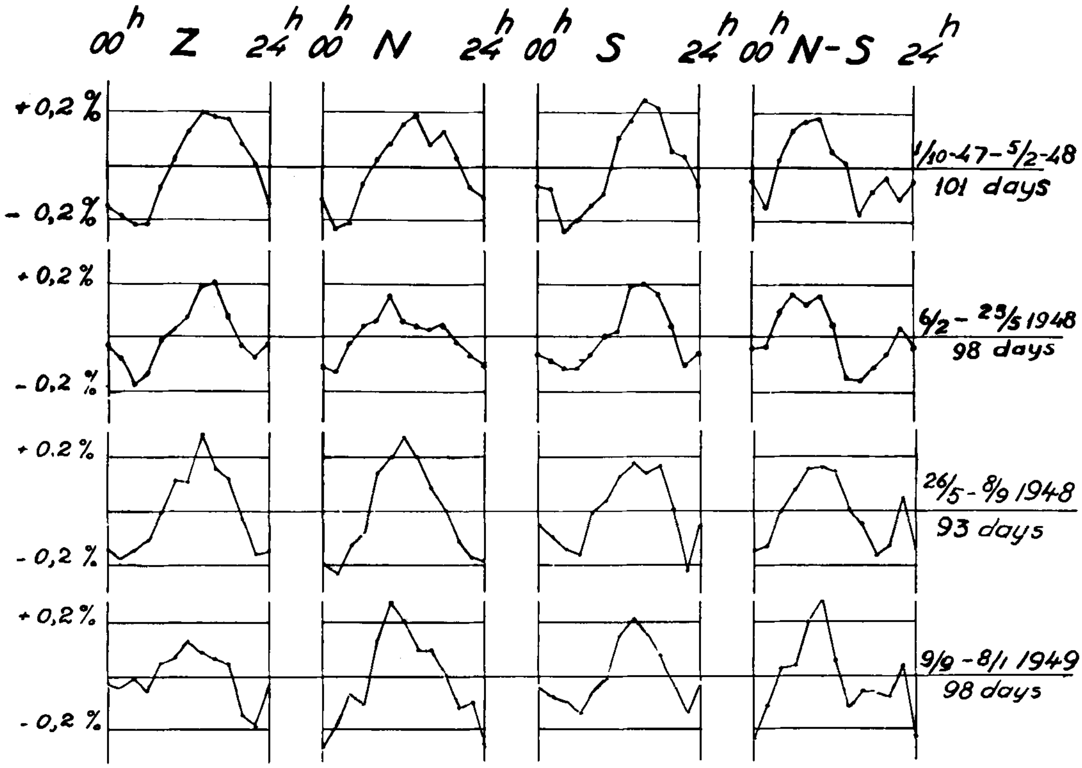

Fig. 4. Curves showing the diurnal variation during periods of about 100 days.

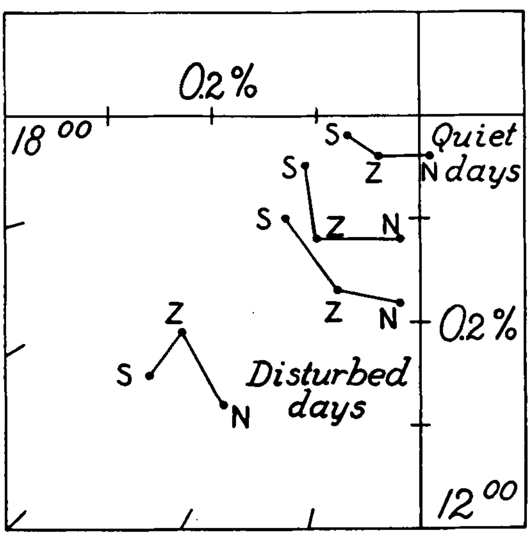

Fig. 5. Harmonic dial diagram, showing mean values of diurnal variation during days grouped together according to C. R. activity.

index 5 or 4. 133 days have the index 3 or 2 and, finally, 87 quiet days have the index 0 or 1.

Tab. IV which gives the number of cases where disturbed and quiet days occur consecutively makes it evident that the amplitudes, as mentioned above, are not distributed at random.

Fig. 5 shows the mean values of the diurnal variation for the four groups of days. This analysis gives the result that *the phase of the variation is nearly the same during quiet and disturbed days*, and indicates that even for quiet days there is a phase difference between the different directions.

Table IV

	Consecutive days				Total
	1	2	3	4	
Disturbed . .	29	12	5	1	72
Quiet	36	13	3	4	87

As yet there is no generally accepted interpretation of the diurnal variation of C. R. From the fact that the variation is not the same in different directions it is obvious that atmospheric effects alone cannot be responsible for the variation. Furthermore, the heating of the atmosphere during the afternoon seems likely to give a variation which reaches its maximum during the early hours of the morning. It seems likely that the observed diurnal variation must be interpreted as being due to some radiation anisotropy which is closely related to the sun. The fact that the amplitude of the variation is very often large during consecutive days indicates that *the strength of this anisotropy varies from time to time*.

As a consequence of new ideas on the generation of C. R. (ALFVÉN, RICHTMEYER, TELLER, 1949) it seems likely that the variation may be associated with the electrodynamical conditions prevailing in the region around the sun. According to ALFVÉN, the particle beams emitted from the sun during magnetic storms are associated with electric fields with potential differences as high as 10^9 volts. ALFVÉN has interpreted the change of C. R. intensity during a magnetic storm as being due to such electric fields (1946). If this interpretation is correct the same argument would apply to the diurnal variation, and it ought to be possible to find some relation between the diurnal variation of C. R. and the structure of the electric fields as revealed by magnetic disturbances and world-wide changes of C. R. intensity.

REFERENCES

ALFVÉN and MALMFORS, 1943: Directional measurements of cosmic radiation, Ark. f. mat., astr. o. fys. 29 A, N:o 24.

ALFVÉN, 1946: Changes in cosmic ray intensity associated with magnetic storms, Nature, **158**, 618.

ALFVÉN, RICHTMYER, TELLER, 1949: On the origin of cosmic rays», Phys. Rev. **75**, 892.

BLACKETT, 1938: On the instability of the barytron and the temperature effect of cosmic rays, Phys. Rev. **54**, 973.

DUPERIER, 1945: The geophysical aspect of cosmic rays, Proc. Phys. Soc. **57**, 464.

DUPERIER, 1948: The temperature effect on cosmic-ray intensity and the height of meson formation, Proc. Phys. Soc. **61**, 34.

KOLHÖRSTER, 1941: Der Tagesgang der Höhenstrahlung, Phys. Zs. **42**, 55.