The Magnetic Storm Effects and the Interplanetary Electromagnetic State

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(Manuscript received December 19, 1956)

Abstract

The electric field of the beam of rarified ionised gas ejected from the sun has been invoked by Alfvén in connection with geomagnetic storms and aurorae. An attempt is made to study the effects of this electric field on cosmic rays. From a study of the ionization chamber records published by Carnegie Institution for the years 1945 and 1946, it appears that the deceleration in the electric field seems to be the most important among the types of effects expected in cosmic rays.

The study reveals that it is possible to attribute the same mechanism, namely, the beam, to explain both the 27 day variation as well as Forbush decreases. The maximum (or minimum) of cosmic ray intensity preceeds the maximum (or minimum) of Kp by about 4—6 days. The direction of the electric field of the beam is also discussed.

Introduction

The vital link in many phenomena involving solar terrestrial relationships, appears to be the electromagnetic state in the interplanetary space. The solar activity appears, to a large extent, to govern the electric and magnetic fields in interplanetary space. The beams supposed to be emitted from the sun consist of ionised rarified gas. A frozen magnetic field and an electric field due to polarisation are associated with the beams (ALFVÉN 1950, 1954, 1955).

There is fairly good agreement that magnetic storms, aurorae and several other ionospheric phenomena are produced by interplanetary ionized beams or clouds. Certain types of cosmic ray variations could also be attributed to the same. The cosmic ray decreases occurring with magnetic storms as well as the 27 day decreases of cosmic ray intensity could be interpreted as modulation effects produced by the deceleration of cosmic rays in the beams from the sun. Hence cosmic rays turn out to be a tool to explore the electromagnetic state in the interplanetary space.

Beam Model

Occurrences on the sun like solar flares, central meridian passage of sunspots etc. are followed a day later by disturbances on the earth like magnetic storms and aurorae. This led to the concept of beams ejected from the sun, consisting of ionized rarified gas as was first suggested by Schuster. The properties of such a beam have been studied by Chapman and Ferraro (see CHAPMAN and BARTELS, 1940) under the assumption that the magnetic field within the beam is zero.

ALFVÉN (1950) has pointed out that the field within the beam cannot be zero, because the beam originates at the solar surface where magnetic fields exist. It is natural to presume that the ionized gas of the beam is initially permeated by a magnetic field, and this field would be frozen within the beam, since the conductivity of the beam is large. Alfvén has pointed out that due to the motion with velocity v_b, the beam appears to an observer on the earth to be electrically polarized (see Fig. 1). The electric field is given by

$$\vec{E} = -\frac{1}{c} \cdot \vec{v}_b \times \vec{H} \qquad (1)$$

The electric field is, according to ALFVÉN (1950, 54 and 55) the most important property of the beam, and the essential features of magnetic storms and aurorae have been explained on this basis.

Since storm variations are observed at all latitudes above the knee (FORBUSH 1938, FORBUSH *et al.* 1950) and even near the geomagnetic pole (SINGER 1954) they cannot be caused by a change in the geomagnetic field. Hence it is natural to assume that the cosmic rays are affected already in the interplanetary space, before they reach the earth. Such an effect could be produced by the electric field in the beam, and BRUNBERG and DATTNER (1954) have explained the features of the cosmic ray storm on this basis. The change in intensity $\triangle I$, produced by cosmic ray particles passing the beam, is given by the following equation, as pointed out by ALFVÉN (1954)

$$\triangle I = k \cdot I \cdot V_b / V_o = \frac{k \cdot I \cdot Eb}{V_o} \qquad (2)$$

where I is the measured intensity, V_b is the voltage difference across the beam and is given by $E.\ b$, E is the electic field, b is the breadth of the beam in the direction of E, V_o is the energy of the cosmic ray particles, and k is a constant depending on the measuring device. ALFVÉN (1954) has tentatively taken a value 3 for k, while a later calculation by LUNDQUIST (1954) gives a value 4.

If the beam emitted from the sun continuously is rotating with it, then, from eq. (2), it can easily be derived that the relative decrease in intensity per day is given by the following equation:

$$-\frac{\triangle I}{I} = \frac{k \cdot E}{V_o} \cdot \frac{2\pi R}{27} \qquad (3)$$

where R, the earth's orbital radius $= 1.5 \times 10^{13}$ cm, and E is the component of the electric field along the earth's orbit. This equation shows that in principle the electric field strength E can be expressed in terms of measurable quantities.

The existence and importance of this electric field is, however, still a matter of discussion. Therefore. eq (3) should rather be considered as an expression of one physical effect attributed to the electric field theory, and the correlation between this effect and other effects due to the same cause be studied by statistical methods. According to the electric field theory, one such other effect is the occurrence of magnetic storms and aurorae. In a general manner, we should expect disturbances in the geomagnetic field to vary in the same way as $\triangle I/I$, and the purpose of the present paper is to study this relation more precisely.

Magnetic Activity and 27 day recurrence of cosmic rays

BARTELS (1938) has devised an arbitrary but consistent method of expressing the deviations of the geomagnetic field from the averaged intensity on undisturbed days. The deviations have been characterised by a scale from 0 to 9, corresponding to the range from a very quiet day to an extremely disturbed day. The average deviations of field intensity for three hour intervals are available for a number of stations in the world. These are known as the daily K figures for the various stations. A central authority prepares average three hourly K values on a world basis, from the observations made available from all the magnetic observatories. This average Kp is the planetary K index (BARTELS 1949).

For the present study of cosmic rays one could choose either the maximum value of Kp on any day or the Kp sums on any day as a fair measure of the geomagnetic disturbance. In general it is found that the two show similar behavior from day to day. We have chosen Kp maximum values. If Kp could be taken as a fair measure of the geomagnetic disturbance, the relative variation $\triangle I/I$ should follow the changes in Kp in a general way.

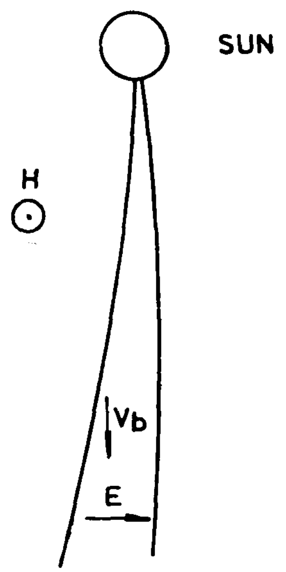

Fig. 1. Storm producing beam, emitted from the sun. (Equatorial plane).

If the direction of the electric field is as is shown in Fig. 1, there would be a continuous decrease in the cosmic ray intensity as long as the earth is inside the beam, and for a reversed electric field, there would be a continuous increase as long as the earth is in the beam. The beam as has been put forward by Alfvén would reveal a continuous decrease, and this would coincide with a high value of K_p in a general way.

Another measure of the geomagnetic disturbance could be the polar distance of the auroral zone. It is well-known that there is a strong connection between the magnetic storms and aurorae. During very strong magnetic storms the auroral zone is widened and aurorae are visible at lower latitudes. It would therefore be worthwhile to look at the problem from this angle also.

The recurrence tendency of moderate geomagnetic storms is well-known (CHREE 1913, CHREE and STAGG 1928, BARTELS 1935). NEWTON (1949) has pointed out that there is strong and fairly precise 27 day recurrence tendency of the smaller magnetic storms, especially those without sudden commencement onset. NEWTON and MILSOM (1954) have pointed out the same, and have also drawn attention to the fact that even small geomagnetic storms with sudden commencement sometimes exhibit short recurrence sequences.

The 27 day recurrence tendency in cosmic rays is well established by the work of MONK and COMPTON (1939), BROXON (1941), HOGG (1949), SIMPSON (1952 a, b, 1953) and others.

The association between geomagnetic storms and cosmic ray storms have also been studied by a number of people. MESSERSCHMIDT (1933) and STEINMAURER and GRAZIADEI (1933) were the first to notice this relation. The worldwide nature of cosmic ray changes during magnetic storms was pointed out by FORBUSH (1937), and HESS and DEMMELMAIR (1937).

The work of Forbush, Hess and others shows that there are a large number of cosmic ray decreases which are associated with magnetic storms. The evidence so far available shows that the relationship between cosmic ray intensity changes and geomagnetic disturbances is not accidental. However, it should be borne in mind that there have been some exceptions. SIMPSON (1954) has pointed out some cases of cosmic ray decreases without any geomagnetic storms. There has also been in 1937 a geomagnetic storm without any appreciable effect in cosmic rays (FORBUSH 1938 a). These special cases need careful investigation and would be considered separately in a later paper.

Data

The data chosen for analysis are the Ionisation Chamber Records published by the Carnegie Institution (1948). The years selected are 1945 and 1946. The former corresponds to the beginning of the new solar cycle since 1944 was the year of minimum solar activity. There was no major magnetic storm during that year. The only storm mentioned occurred on March 28th. From Fig. 2 showing the daily mean cosmic ray intensities for the years 1945 and 1946, it can be seen that the variation in intensity from day to day is rather small for 1945. The year 1946 is unique in that a series of heavy Forbush decreases started in Feb. and lasted for six months. So the period February to October have been taken up for analysis in order to have a typical heavily disturbed period in contrast to 1945. The data from Huancayo and Cheltenham have been utilised for 1945, while the data from Godhavn

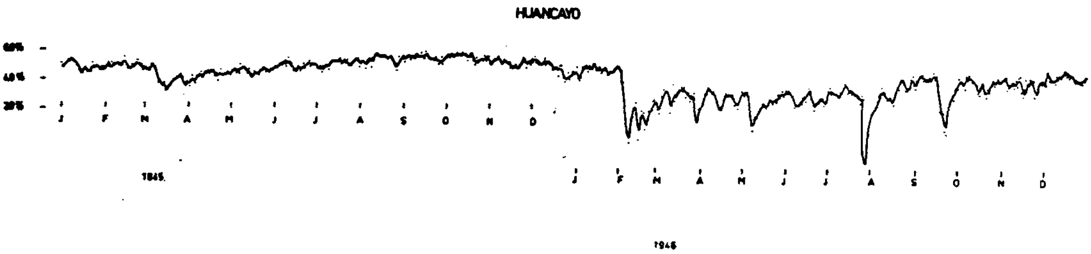

Fig. 2. Daily mean cosmic ray intensities at Huancayo for 1945 and 1946.

have also been used for 1946, in addition to the other two.

Chree analysis

The method of analysis is the one originally devised by Chree for the analysis of geomagnetic character figures. The method requires the addition of intensity on all days which exhibit a minimum (or maximum) intensity. The addition is done for the days following and preceding the selected zero days. The investigation could be extended to any number of days on either side of the zero days. This analysis reveals any recurrence tendency among the minima (or maxima) of the mean daily values and also gives the average period of the recurrence tendency. This method is free from any preconceived ideas about the length and significance of the recurrence tendency.

Five days of minimum intensity per month are chosen, and the values corresponding to those days are written down one below the other in a vertical column designated "o" day. The values for the days following these selected zero days are written down in a sequence to the right, and designated as + 1, + 2, + 3 ... day columns. A similar procedure is adopted for days preceding the zero days, and the values are written to the left of o day column, and are called − 1, − 2, − 3 ... columns. The average value is found for each column. An averaging of these values for three days is done to smoothen the data. Thus we get the average values corresponding to o day, +3, +6, +9 ... days, and −3, −6, −9 ... days. These values are plotted on a graph against the corresponding days. The analysis can also be done corresponding to 5 days of maximum intensity per month.

As pointed out earlier the maximum value of K_p for each day for the same period has been used. For the Chree Analysis the same zero days as were chosen from cosmic ray data have been taken.

The same zero days determined for Huancayo have been used for the other stations as well as for K_p. The days have been selected from Huancayo, because the data are not mixed up with seasonal variation as has been pointed out by FORBUSH (1954). Since the phenomenon is world-wide, the reasonable procedure to adopt appears to be to choose the same days for all the stations.

Results and Discussion

The result of the Chree Analysis for the year 1945 for Huancayo corresponding to 5 minimum intensity days per month is shown in Fig. 3. The top curve shows the cosmic

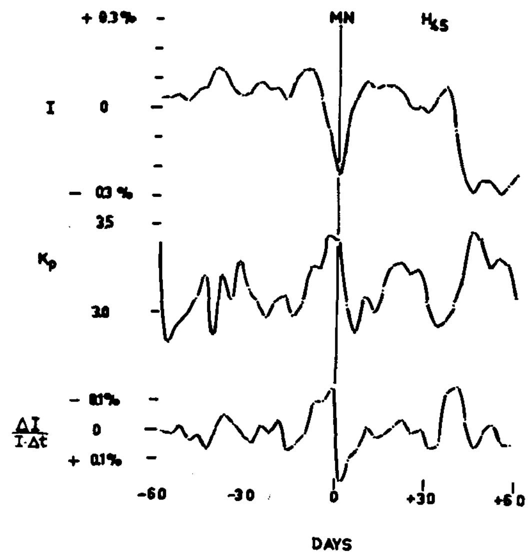

Fig. 3. Chree Analysis for Huancayo for 1945 corresponding to five minimum intensity days per month. The top curve refers to cosmic ray intensity, middle one to K_p, and the bottom one to the relative decrease in intensity $-\Delta I/I$ per day, shown reversed.

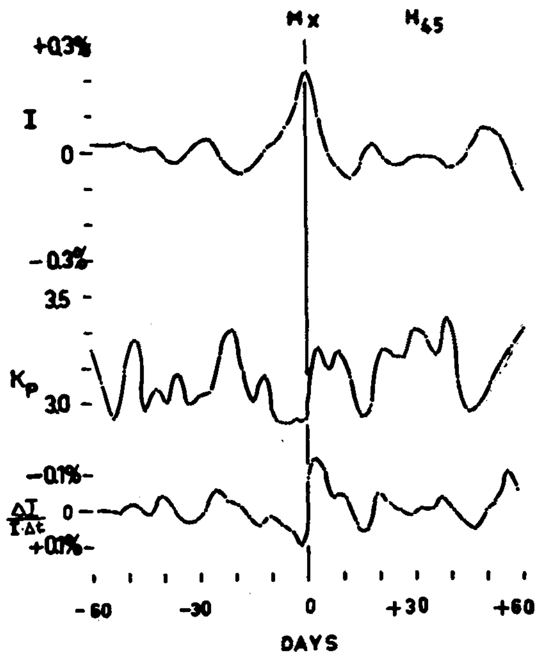

Fig. 4. Chree Analysis for Huancayo for 1945 corresponding to five maximum intensity days per month. The top curve refers to cosmic ray intensity, middle one to K_p, and the bottom one to the relative decrease in intensity $-\triangle I/I$ per day, shown reversed.

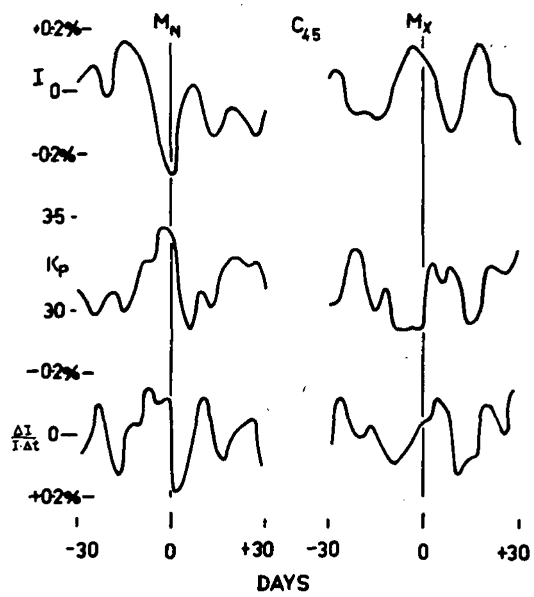

Fig. 5. Chree Analysis for Cheltenham for 1945 corresponding to five days of minimum as well as maximum days of intensity. The top curve refers to cosmic ray intensity, middle one to K_p, and the bottom one to the relative decrease in intensity $-\triangle I/I$ per day, shown reversed.

ray intensity, the middle one, the K_p, and the bottom one, the relative decrease in intensity per day, $-\triangle I/I$. The scale is reversed for the bottom curve to show the correspondence with K_p better. Fig. 4 shows the results for Huancayo for the same year corresponding to the 5 maximum intensity days per month, and Fig. 5 for the same year for Cheltenham for both the cases. The analysis has been done from -60 to $+60$ days in the case of Huancayo, while it has been done only from -30 to $+30$ days in the case of Cheltenham.

The fair agreement between $-\triangle I/I$ and K_p can be seen. The agreement is extremely good, if one considers the difficulty of choosing the minimum and maximum intensity days for this period. Fig. 2 shows how small the deviations are, and how difficult it is to choose the zero days. Table 1 gives the correlation

Table 1. Correlation coefficients for 1945 between

No	Station	I and K_p	$-\frac{\triangle I}{I}$ per day and K_p	I and K_p	$-\frac{\triangle I}{I}$ per day and K_p
		Min. Intensity Days		Max. Intensity Days	
		From —30 to +30 days			
1.	Huancayo	$-.34\pm.03$	$+.56\pm.02$	$-.49\pm.02$	$+.65\pm.02$
2.	Cheltenham	$-.59\pm.02$	$+.26\pm.01$	$-.68\pm.02$	$+.48\pm.02$
		From —15 to +15 days			
1.	Huancayo	$-.57\pm.04$	$+.59\pm.03$	$-.36\pm.05$	$+.52\pm.04$
2.	Cheltenham	$-.53\pm.04$	$+.33\pm.05$	$-.59\pm.04$	$+.40\pm.04$

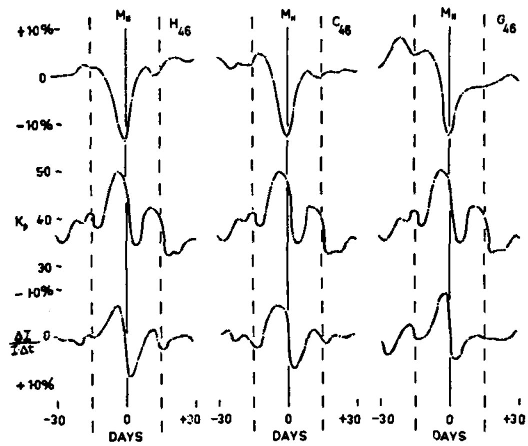

Fig. 6. Chree Analysis for Huancayo, Cheltenham, and Godhavn for 1946 corresponding to five days of minimum intensity per month. The top curve refers to cosmic ray intensity, the middle one to K_p, and the bottom one to the relative decrease $-\triangle I/I$ per day, shown reversed.

between the top curve and middle curve, and that between the bottom curve and the middle curve.

The results of the analysis for 1946 for all the three stations corresponding to 5 minimum intensity days per month are shown in Fig. 6. The same results as observed for the data of 1945 are seen here also to an even more pronounced degree. The correlation is easier for study during 1946 because there is no difficulty about the selection of the zero days.

Table 2 gives the correlation between the curves. The values are extremely good for both Cheltenham and Godhavn. The slightly lower value for Huancayo is understandable because there are quite a few days in Huancayo when a number of bihourly values are missing and hence the daily means are obtained from the rest of the values available. The improvement in the correlation when we consider ± 14 days instead of ± 30 days is connected with the general experience that usually in 27 days recurrence figures, a secondary series appears after about 14 days, and this complicates the issue.

The influence of the beam on cosmic rays appears to be rather complicated. The deceleration of cosmic rays in the electric field of the beam is only one of the effects. In the idealised case, if no other effects are present except the deceleration in the electric field, the variation in K_p and cosmic rays would be as shown in Fig. 7, where relatively higher K_p values accompany the fall in cosmic ray intensity. This is the average state of affairs as revealed by Figs 3, 4 and 5. There are however exceptions and as pointed out by ALFVÉN (1956) at least two other effects may tend to mask the electric field effect. These could very well conceal the correlation between the relative decrease $-\triangle I/I$ and K_p. Alfvén has pointed out that in addition to the electric field effect there could be a magnetic field effect due to the difference in the magnetic field inside and outside the beam, and also that cosmic ray particles may be captured in the beam.

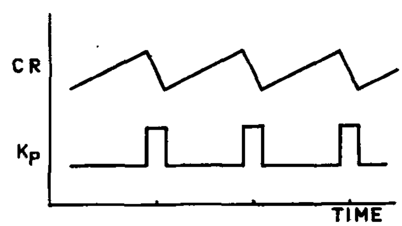

Fig. 7. The variation of cosmic ray intensity and K_p in an idealised case when only the deceleration in the electric field of the beam is considered.

Table 2. Correlation coefficients for 1946 between

No	Station	I and K_p	$-\frac{\Delta I}{I}$ per day and K_p	I and K_p	$-\frac{\Delta I}{I}$ per day and K_p
		Min. Intensity Days			
		From − 30 to + 30 days		From − 15 to + 15	
1.	Huancayo	−.72±.01	+.58±.02	−.63±.03	+.79±.02
2.	Cheltenham	−.48±.02	+.65±.02	−.42±.05	+.87±.01
3.	Godhavn	−.16±.01	+.76±.01	−.14±.05	+.90±.01

Correlation between individual decreases in cosmic ray intensity and K_p.

As has been pointed out by ALFVÉN (1956), it is difficult to look at the individual decreases due to the fact that there may also be effects other than deceleration in the electric field. It is much easier to average out over a number of decreases, since this gives us an idea whether the deceleration effect is the preponderant one. Nevertheless, it has been thought worthwhile to look at the individual decreases, to see whether one can disentangle the electric field effect.

Table 3 shows the results for three day averages as well as day to day values. The correlation between I and K_p is in general negative, and the apparent correlation between $-\frac{\Delta I}{I}$ (the negative sign indicates decrease) and K_p in general is positive since the curve $-\Delta I/I$ has been reversed and plotted. There are a couple of cases when there is a high positive correlation between I and K_p. These have to be looked into in greater detail to see whether the other effects are more predominant that the electric field deceleration effect.

Forbush Decreases

We consider that the 27 day variations which have a recurrence tendency and the heavy Forbush decreases which are presumed to have no recurrence tendency are essentially due to the same effect; viz., the deceleration in the electric field in the interplanetary space; but only the latter is on a much larger scale. A recurrence tendency in Forbush decreases has been reported by SINGER (1956) during May—June 1951 from a comparison of data from Berkeley, Manchester, and a polar station. It would be extremely interesting to look for such occurrences. This observation would give additional support for the view that the Forbush decreases are also of the same nature as the 27 day variations, but differing only in the matter of degree.

It is perhaps reasonable to expect that the heavy Forbush decreases would not have a recurrence tendency. This would be clear from the following calculation. The magnetic flux $d\phi/dt$ transported per unit time across the earth's orbit by a storm-producing beam is given by the following equation:

$$d\phi/dt = -Hb \cdot v_b = -c \cdot V_b \qquad (3)$$

Table 3. Huancayo 1946. Correlation coefficient between

No	Min. Intensity on	(3 Day Averages) I and K_p	(3 Day Averages) $-\frac{\Delta I}{I}$ per day and K_p	(Day to Day values) I and K_p	(Day to Day values) $-\frac{\Delta I}{I}$ per day and K_p
1.	Feb. — 8	$-.81\pm.02$	$-.12\pm.06$	$-.56\pm.04$	$0\ \pm.05$
2.	Feb. — 16	$-.30\pm.05$	$+.67\pm.03$	$-.35\pm.05$	$+.76\pm.02$
3.	Feb. — 21	$-.60\pm.04$	$+.37\pm.05$	$-.45\pm.05$	$+.56\pm.04$
4.	Mar. — 2	$-.11\pm.06$	$-.41\pm.05$	$-.18\pm.38$	$-.02\pm.06$
5.	Mar. — 10	$-.70\pm.03$	$+.03\pm.06$	$-.69\pm.03$	$-.22\pm.03$
6.	Mar. — 29	$+.31\pm.05$	$+.72\pm.03$	$0\ \pm.05$	$+.45\pm.05$
7.	Apr. — 15	$-.83\pm.02$	$+.16\pm.06$	$-.76\pm.02$	$+.04\pm.06$
8.	Apr. — 27	$-.23\pm.06$	$+.65\pm.03$	$0\ \pm.05$	$+.40\pm.05$
9.	May — 8	$-.68\pm.03$	$+.31\pm.05$	$-.68\pm.03$	$+.28\pm.01$
10,	June — 9	$-.68\pm.03$	$+.31\pm.05$	$-.66\pm.03$	$+.24\pm.02$
11.	June — 21	$+.76\pm.03$	$+.25\pm.06$	$+.65\pm.03$	$-.07\pm.06$
12.	June — 29	$-.77\pm.03$	$+.16\pm.06$	$-.40\pm.05$	$+.35\pm.05$
13.	July — 9	$-.39\pm.05$	$+.15\pm.06$	$-.26\pm.02$	$+.40\pm.05$
14.	July — 28	$-.69\pm.03$	$+.50\pm.05$	$-.42+,05$	$+.60\pm.04$
15.	Aug. — 15	$-.97\pm.00$	$+.53\pm.04$	$-.60\pm.04$	$+.42\pm.05$
16.	Aug. — 25	$+.19\pm.06$	$+.25\pm.06$	$+.09\pm.06$	$+.55\pm.04$
17.	Sep. — 1	$+.68\pm.03$	$+.43\pm.05$	$+.18\pm.04$	$+.83\pm.02$
18.	Sep. — 23	$-.39\pm.05$	$+.35\pm.05$	$-.40\pm.05$	$+.14\pm.05$

where the letters refer to the same quantities as explained in connection with the equations (1) and (2). The negative sign indicates that the flux is being transported outwards. If we take for example the decrease of about 7.3 % at Huancayo on July 26—27, 1946, this would correspond to a voltage across the beam of 7.3×10^8 volts or $7.3 \times 10^8/300$ esu. Hence we obtain for $\frac{d\phi}{dt} = 7.3 \times 10^{16}$ gauss cm² sec⁻¹. Let us consider the general solar magnetic field to be due to a homogeneously magnetised body with a polar field H_p. Its total flux is given by the following equation

$$\phi = \pi R_\odot^2 H_p \qquad (4)$$

where $R_\odot$ is the radius of the sun. There is a difference of opinion about the value of H_p and it is still a matter of discussion. If we take, for example, a value of 10 gauss for H_p, $\phi = 1.5 \cdot 10^{23}$ gauss cm², the beam would empty the whole flux in 2×10^6 seconds, which corresponds to less than 27 days unless replanished. If we take a value of 1 gauss, there would be an order of 10 less in the time taken to empty the beam. It is therefore reasonable to expect that such heavy decreases cannot have a recurrence tendency. If we take a decrease of about 3 % then it would take about 5×10^6 seconds. Such decreases could last even two rotations. So a recurrence tendency could occur in such cases.

The Electric and Magnetic Fields in the Beam

It is possible to get some rough estimate of the order of the electric and magnetic fields in the beam. The uncertainties involved are the velocity of the particles in the beam and the average primary cosmic ray energy. The average velocity of the particles in transit from the sun could be reasonably taken to range between about 500 km/sec and 1,700 km/sec (ALLEN 1955, ROBERTS 1954, PAWSEY and BRACEWELL 1955).

There appears to be a view that the normal recurrent storms are associated with the lower order of velocities, while the bigger storms are associated with the higher order of velocities. Calculations have been made for velocities 2×10^8, 10^8, 5×10^7, and 10^7 cm per sec. It appears reasonable to take for the average primary energy a value 3×10^{10} ev. However calculations have been done for two other cases 2×10^{10}, and 4×10^{10} to cover the range of possible values for the average primary energy.

Table 4 gives the order of the electric and magnetic fields in the beam near the earth's orbit for the year 1945. The average relative decrease in intensity obtained from the Chree diagram has been used in the calculations. Both the cases corresponding to the maximum and minimum intensity days have been considered.

Similarly Table 5 gives the order of the fields for the year 1946 corresponding to minimum intensity days only as the Chree analysis has been done only for that case. It has been pointed out earlier that during 1945 there were no great storms. If we ascribe the lower order of velocities, say, between 5×10^7 and 10^8 cm per sec as a reasonable range, then we get a value for the electric field between 0.5 and 0.9 μ volt/cm, and a value for the mag-

Calculation of the electric and magnetic fields whithin the beam near the earth's orbit corresponding to different average primary cosmic ray energies and corresponding to different velocities of particles in the beam, with the relative decrease in cosmic ray intensity taken from the Chree diagram.

Table 4 — 1945

	Decrease	Velocity cm/sec	$V_0 = 2 \times 10^{10}$ e. v.		$V_0 = 3 \times 10^{10}$ e. v.		$V_0 = 4 \times 10^{10}$ e. v.	
			E	H	E	H	E	H
				gauss		gauss		gauss
Max I days	·30 % in 12 days (ie .025 %)	2×10^8	0.36 micro volt/cm	$.18 \times 10^{-6}$	0.54 micro volt/cm	$.27 \times 10^{-6}$	0.72 micro volt/cm	$.36 \times 10^{-6}$
		10^8		$.36 \times 10^{-6}$		$.54 \times 10^{-6}$		$.72 \times 10^{-6}$
		5×10^7		$.72 \times 10^{-6}$		1.08×10^{-6}		1.44×10^{-6}
		10^7		3.6×10^{-6}		5.4×10^{-6}		7.2×10^{-6}
Min I days	·36 % in 9 days (ie .04 %)	2×10^8	0.57 micro volt/cm	$.29 \times 10^{-6}$	0.86 micro volt/cm	$.44 \times 10^{-6}$	1.14 micro volt/cm	$.58 \times 10^{-6}$
		10^8		$.58 \times 10^{-6}$		$.88 \times 10^{-6}$		1.16×10^{-6}
		5×10^7		1.16×10^{-6}		1.76×10^{-6}		2.32×10^{-6}
		10^7		5.8×10^{-6}		8.8×10^{-6}		11.6×10^{-6}

Table 5 — 1946

	Decrease	Velocity cm/sec	$V_0 = 2 \times 10^{10}$ e. v.		$V_0 = 3 \times 10^{10}$ e. v.		$V_0 = 4 \times 10^{10}$ e. v.	
			E	H	E	H	E	H
				gauss		gauss		gauss
Min I days	1.40 % in 9 days (.16 %)	2×10^8	2.20 μ volt/cm	1.10×10^{-6}	3.30 μ volt/cm	1.65×10^{-6}	4.40 μ volt/cm	2.20×10^{-6}
		10^8		2.20×10^{-6}		3.30×10^{-6}		4.40×10^{-6}
		5×10^7		$4.40\% 10^{-6}$		6.60×10^{-6}		8.80×10^{-6}
		10^7		22.0×10^{-6}		33.0×10^{-6}		44.0×10^{-6}
Min I days	1.55 % in 12 days (.13 %)	2×10^8	1.87 μ volt/cm	$.93 \times 10^{-6}$	2.80 μ volt/cm	1.40×10^{-6}	3.74 μ volt/cm	1.86×10^{-6}
		10^8		1.86×10^{-6}		2.80×10^{-6}		3.72×10^{-6}
		5×10^7		3.72×10^{-6}		5.60×10^{-6}		7.44×10^{-6}
		10^7		18.6×10^{-6}		28.0×10^{-6}		37.2×10^{-6}

netic field between 0.7×10^{-6} and 1.4×10^{-6} gauss. For the year 1946 the corresponding values would be 3.3 μ volt/cm and 3×10^{-6} and 7×10^{-6} gauss. These are based on the following assumptions: 1) The velocity of the particles in the beam is assumed to lie in the range 5×10^7 and 10^8 cm/sec. 2) The average primary cosmic ray energy is taken to be 3×10^{10} ev. 3) The deceleration in the electric field takes place not far from the earth's orbit.

It should be pointed out that during individual storms, the conditions could be very much different from the average picture we get from the Chree analysis where we have superimposed a number of storms. We could expect much larger values for the fields during these individual cases.

For the year 1945, only two storms are worth considering. They are 1) a decrease of 1.2 % from March 27th to 28th, and 2) decrease of 1.1 % from March 8th to 10th. The values for the fields in the beam are given in Table 6. It can be seen how much the individual cases could differ from the average.

The year 1946 provides a number of extreme cases for the evaluation of the fields in the beam. The values are given in Table 7. As in 1945, here also the individual cases show great departures from the average for the year.

If we consider the case when there is only the solar dipole field, then the value of the field at the earth's orbital distance can be calculated. They are 0.5×10^{-7} gauss for a solar dipole field of 1 gauss at the pole, and 0.5×10^{-6} gauss for a field of 10 gauss at the pole. If it is reasonable to accept the view that the recurrent storms are associated with the lower velocity of particles in the beam and if we take say 700 km/sec as the average velocity, then the average value for the magnetic field near the earth is about 1.0×10^{-6} gauss during 1945. This is slightly greater than the order of the field if there were only a pure solar dipole field of 10 gauss.

Of course as pointed out earlier, the magnetic field during individual storms could be much higher than the average value. However it is not unlikely that there could be the existence of only the undisturbed solar dipole field during the low solar activity period except when it is disturbed by the beams. It would therefore be interesting to look into the interplanetary electromagnetic conditions during 1943—44, the period of minimum solar activity.

It is an open question whether the field frozen in the beam is the sun's general magnetic field or the local field of the region of produc-

Calculation of the electric and magnetic fields in the beam during individual decreases
Table 6 — 1945

No	Date	Total decrease %	Days decrease lasted	E μ volt per cm	H $\times 10^{-6}$ gauss			
					$v = 2 \times 10^8$	$v = 10^8$	$v = 5 \times 10^7$	$v = 10^7$
I	March 27—28	1.2	1	25.8	12.9	24.9	49.8	249.0
II	March 8—10	1.1	2	11.8	5.9	11.9	23.6	118.0

Table 7 — 1946

No	Date	Total decrease %	Days decrease lasted	E μ volt per cm	$H \times 10^{-6}$ gauss			
					$v = 2 \times 10^8$	$v = 10^8$	$v = 5 \times 10^7$	$v = 10^7$
I	Feb 3—8	5.0	5	21.5	10.75	21.5	43.0	215.0
II	13—15	2.6	2	27.9	13.95	27.9	55.8	279.0
III	19—20	1.2	1	12.9	6.45	12.9	25.8	129.0
IV	Feb. 27—March 2	0.9	3	9.7	4.85	9.7	19.4	97.0
V	March 8—10	1.5	2	16.1	8.05	16.1	32.2	161.0
VI	27—28	2.4	1	25.8	12.90	25.8	51.6	258.0
VII	Apr. 6—9	0.4	3	2.9	1.45	2.9	5.8	29.0
VIII	10—14	1.2	4	6.4	3.20	6.4	12.8	64.0
IX	May 4—8	2.7	4	29.0	14.50	29.0	58.0	290.0
X	June 6—7	0.7	1	15.0	7.50	15.0	30.0	150.0
XI	17—21	1.5	4	8.1	4.05	8.1	16.2	81.0
XII	July 26—27	7.3	1	156.8	78.4	156.8	313.6	1 568.0
XIII	Aug. 8—12	0.8	4	4.3	2.15	4.3	8.6	43.0
XIV	14—16	0.5	2	5.4	2.70	5.4	10.8	54.0
XV	22—25	0.8	3	5.7	2.85	5.7	11.4	57.0
XVI	Aug. 30—Sept. 3	0.9	2	9.7	4.85	9.7	19.4	97.0
XVII	Sept. 16—19	2.4	3	17.2	8.60	17.2	34.4	172.0
XVIII	21—23	1.5	2	16.1	8.05	16.1	32.2	161.0
XIX	Oct. 14—15	0.6	1	12.9	6.45	12.9	25.8	129.0
XX	19—21	0.9	2	9.7	4.85	9.7	19.4	97.0

tion of beams. It is expected that the field frozen on an average would be the general field of the sun. The direction of the electric field would be as shown in Fig. 1. The study of aurorae gives this direction. In addition, the decrease in cosmic rays shows that the direction of the field has to be as in Fig. 1. If the direction of the field is reversed, it should reveal itself in the study of aurorae. In the case of cosmic rays, an increase in intensity would be observed when the beam passes the earth. On an average, this is not observed.

Correlation between I. — $\triangle I/I$ and K_p

From the Chree analysis for the two years we have seen that there is a negative correlation between I and K_p and an apparent positive correlation between $-\triangle I/I$ and K_p, since the curve $-\triangle I/I$ is plotted reversed. The minimum (or maximum) of cosmic ray intensity precedes that of K_p by about 6 days. This agrees with the results of Simpson (1954) and Kane (1955) but differs from that of Van Heerdan-Thambyah Pillai (1955). It should be pointed out that the periods of study are different. Anyhow it is rather important to look into this matter carefully. It could be asked whether it would not be possible to get a better correlation between I and K_p by displacing the K_p curve in the negative direction by about 6 days. This would be justifiable if some sound physical reason could be found for such a procedure. A lag of about one day could be permissible since it takes about that time for the disturbance on the sun to be observed at the earth by the effects. Moreover we have already pointed out the physical reasons for the comparison of $-\triangle I/I$ and K_p.

27 day Variation

The beam picture gives an explanation for the 27 day variation. The fact that the amplitude of this variation becomes extremely small during low solar activity period (Meyer and Simpson 1954) shows that powerful and very active beams are absent which is reasonable in view of the solar activity.

Conclusions

The following conclusions emerge from the study:

1) The electric field of the beam, which has been invoked by Alfvén, in connection with magnetic storms and aurorae, appear to produce certain types of effect in cosmic rays, of which the deceleration in the electric field seems to be the most important.

2) The study of the cosmic ray data for 1945 and 1946 shows that the relative decrease in its intensity per day seems to follow the changes of the planetary index, K_p, which is a measure of the electric field, as expected from the theory.

3) As an average state of affairs, the electric field seems to have a direction as shown in Fig. 1. It is an open question, whether they could be occasional cases of a reverse electric field.

4) The maximum or minimum of cosmic ray intensity precedes the maximum or minimum of K_p by about 4—6 days. This agrees with the results of Simpson and Kane but differs from those of Van Heerdan and Thambiahpillai. The periods of study are different.

5) It appears reasonable to assume that the same mechanism, namely the beam, could be invoked to explain both the 27 day variation as well as heavy Forbush decreases.

6) The decrease in amplitude of the 27 day variation, and the absence of great storms and heavy Forbush decreases during low solar activity period appears consistent with the activity of the beams.

I wish to thank professor H. Alfvén for his keen interest and to him and Dr. Herlofson for valuable discussions throughout the investigation. I am grateful to the "Statens Tekniska Forskningsråd" for support which has made this investigation possible. I am also thankful to Mrs Bharathi Venkatesan for computational assistance.

BIBLIOGRAPHY

ALFVÉN, H., 1950: *Cosmical Electrodynamics* (Oxford) Ch. VI.
— 1954: On the origin of cosmic radiation, *Tellus* **6**, p. 232.
— 1955: Theory of magnetic storms and aurorae, *Tellus* **7**, p. 50.
— 1956: International Astronomical Union Conference on the Electromagnetic State in Cosmical Physics.
ALLEN, C. W., 1955: *Astrophysical Quantities* (University of London. Athlone Press) p. 129.
BARTELS, J., 1935: *Terr. Mag. and Atmos. Electr.* **40**, p. 1.
— 1938: *Z. Geophysik* V, p. 14.
— 1949: *I. A.T. M. E. Bull.* Washington No. 12 b, p. 97—112.
BRUNBERG, E. Å. and DATTNER, A., 1954: Variations of the cosmic ray intensity during magnetic storms, *Tellus* **6** p. 73 and **6**, p. 254.
BROXON, J. W., 1941: Recurrence Phenomena in Cosmic Rays. *Phys. Rev.* **59**, p. 773.
CARNEGIE INSTITUTION, 1948: Publication 175.
CHREE, C., 1913: *Phil. Trans.* A, **212**, p. 76.
CHREE, C. and STAGG, I. M., 1928: *Phil. Trans.* A, **227**, p. 21.
FORBUSH, S. E., 1937: *Phys. Rev.* **52**, p. 1254.
— 1938 a: *Terr. Magn.* **43**, p. 203.
— 1938 b: *Phys. Rev.* **54**, p. 975.
— 1954: World wide cosmic ray variations 1937—52. *J. Geoph. Res.* **59**, p. 525.
FORBUSH, S. E., STINCHCOMB, T. B. and SCHEIN. M., 1950: The extraordinary increase of cosmic ray intensity on November 19, 1949.
HEERDAN, V. and THAMBYAH PILLAI, 1955: The 27-day recurrence tendency of cosmic ray intensity, *Phil. Mag.* **46**, p. 1238.
HESS, V. F. and DEMMELMAIR, A., 1937: *Nature* **140**, p. 316.
HOGG, A. R., 1949: Memoirs of the Commonwealth Observatory, Camberra, No. 10.
KANE, R, P., 1955: Recurrence phenomenon in the 24-hour variation of cosmic ray intensity, *Phys. Rev.* **98**, p. 130.
LUNDQUIST, S., 1954: A note on the variation of cosmic ray intensity produced by an electric field, *Tellus* **6**, p. 260.
MEYER, P. and SIMPSON, J. A., 1954: Changes in amplitude of the cosmic ray 27-day intensity variation with solar activity, *Phys. Rev.* **96**, p. 1085.
MESSERSCHMIDT, W., 1933: *Z. Phys.* **85**, p. 332.
MONK, A. T. and COMPTON, A. H., 1939: *Rev. Mod. Phys.* **11**, p. 175.
NEWTON, H. W., 1949: Observational aspects of the sunspot-geomagnetic storm relationships, *Month. Not. R.A.S.* **5**, p. 322.
NEWTON, H. W. and MILSOM, A. S., 1954: The distribution of great and small magnetic storms in sunspot cycle, *J. Geophys. Res.* **59**, p. 203.
PAWSEY, J. L., and BRACEWELL, R. N., 1955: Radio Astronomy (Oxford) p. 136.
ROBERTS, J. A., 1954: *Research*, **7**, no. 10, Oct.
SIMPSON, J. A., FONGER, W. and WILCOX, L., 1952 a: A solar component of the primary cosmic rays, *Phys. Rev.* **85**, p. 366.
— 1952 b: Temporal changes of nucleonic component intensity, *Phys. Rev.* **87**, p. 240.
SIMPSON, J. A., FONGER, W. and TREIMAN, S. B., 1953: Cosmic ray intensity time variations and their origin I, *Phys. Rev.* **90**, p. 934.
SIMPSON, J. A., 1954: Cosmic ray intensity time variations and their origin III, *Phys. Rev.* **94**, p. 426.
SINGER, F., 1954: Storm decrease of the cosmic rays at the pole. *Phys. Rev.* p. **95**, 647.
— 1956: Maryland Univ. Phys. Dept., *Techn. Rep.* 40.
STEINMAURER, R. and GRAZIADEI, H. T., 1933: *S. B. Akad. Wiss.*, Wien, **22**, p. 672.