# On the Interpretation of the Diurnal Variation of Cosmic Rays

By E. Å. BRUNBERG and A. DATTNER. The Royal Institute of Technology, Stockholm

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## Abstract

The recorded data of diurnal variation of the cosmic ray intensity are analysed. By using the known deflection of the cosmic ray particles in the geomagnetic field (BRUNBERG and DATTNER 1953) and under an assumption of an anisotropy in the primary cosmic radiation, it is shown that the momentum of the primary radiation and the direction of the anisotropy can be determined.

The anisotropy is explained as an effect due to the distribution of cosmic ray particles rotating with the solar magnetic field as suggested by H. Alfvén.

*The diurnal variation is ascribed to the earth's rotation in the anisotropic distribution of* cosmic ray particles. The theoretical amplitude of this variation is calculated.


Measurements of the intensity of cosmic radiation have demonstrated that there is a solar time diurnal variation with an amplitude of about 0.2 % ("Progress of Cosmic Ray Physics" 1952). Whether a siderial variation exists or not is still an open question. In any case the siderial variation is much smaller than the solar time variation, probably less than one tenth. The diurnal variation is in part an atmospheric effect. The cosmic radiation is absorbed during its passage through the atmosphere and changes in barometric pressure and temperature affect the intensity of cosmic radiation. As the meteorological elements show a diurnal variation the result will be a diurnal variation in cosmic ray intensity. In principle it is possible to correct for this influence. Even if such a correction is applied, however, a residual diurnal variation remains. It might be suspected that this is due to some atmospheric influence for which the correction is unknown, but this possibility can be ruled out, by directional measurements with Geiger-Müller counters. If we measure the cosmic radiation coming from the north and compare this with the radiation from the south, a difference in phase of the diurnal variation is observed, which can not be due to the atmospheric conditions because the rays coming from the north and from the south have passed almost identical atmospheric layer. Such measurements made in Berlin (KOLHÖRSTER 1941), Stockholm (ALFVÉN 1938, ALFVÉN and MALMFORS 1943, MALMFORS 1949), and Manchester (ELLIOT and DOLBEAR 1950, 1951) demonstrate beyond any doubt that the phases of diurnal variation measured from the north and from the south are different. This shows that there is diurnal variation in the primary cosmic radiation.

The next problem is to decide which part of the primary radiation is responsible for the variation. We know that practically all the primary cosmic rays consist of positively charged particles. It is not ruled out, however, that there may also be a small neutral component. The assumption of a neutral anisotropic component is supported by the fact that usually the maximum occurs not very far from noon. The neutral component, which should exhibit a solar time variation would then derive from the sun or its close vicinity. If we measure cosmic radiation by ionization chambers or by counters directed to zenith we must find a maximum of the neutral component occurring exactly at noon because the neutral particles are not deflected by the geomagnetic field.

Although it cannot be ruled out that there is a variation caused by neutral particles there is no positive indication that this is the case. We shall in the following assume that the whole variation is due to the charged particle component of the cosmic radiation. The atmospheric variation and a possible neutral particle component may introduce considerable corrections in the empirical material. But as these are unknown as yet we shall neglect them.

In order to study the charged particle component it is necessary to correct for the deflection of the particles in the geomagnetic field. This correction has been studied thoroughly by BRUNBERG and DATTNER (1953) and the result published in a series of diagrams. It is, however, necessary to know which part of the primary momentum spectrum is responsible for the observed variation, but unfortunately it seems to be unknown. The secondary processes in the atmosphere are not yet quantitatively known and furthermore the different types of apparatus, the different shielding employed, and different altitudes make it likely that all observers do not measure in the same momentum range. It would therefore be advantageous to have a method for analyzing the observed variations in such a way that conclusions could be drawn about which part of the momentum spectrum is responsible for the variation. One way of doing this is shown in the following discussion, which is based on a detailed knowledge of particle orbits in the geomagnetic field, together with the assumption that the diurnal variation is caused by an excess in the primary radiation coming in from one fairly definite direction.

## Determination of the momentum of the variable component

Two different ways could be used and both of them require an assumption that there is only one direction of anisotropy in the primary cosmic radiation responsible for the diurnal variation.

1) Measurements in different directions at one particular station could be analysed and the difference in phase and amplitude in the different directions could be used to find the momentum of the variable component.

2) Comparisons of measurements at different latitudes.

As an application of the first method we will consider some measurements made in Stockholm by MALMFORS in 1948. Three sets of telescopes were directed, the first towards a point 30° to the north of zenith, the second one to a point 30° to the south of zenith and the third to the zenith. The local time for maximum amplitude in the three directions was determined. In fig. 1 the point of observation P is situated in latitude $\lambda$. We consider two coordinate systems, one system $X'$, which is defined by the $x'$-axis pointing to the sun and the $z'$-axis coinciding with the earth's axis of rotation, and another system $X$ with the $x$-axis defined by the intersection of the meridional plan through the point $P$ and the equatorial plane of the earth.

In the $X'$-system the main direction of the anisotropy is defined by $\Psi'_E$ and $\Phi'_N$. In the $X$-system $\Psi_E$ and $\Phi_N$ are angles which determine the direction of the measured cosmic particles far away from the earth. When the $X$-system rotates in relation to $X'$ we measure at the point $P$ a variation of the cosmic ray intensity with a maximum occurring when

$$\Psi'_E = \Psi_E + \Psi_t$$

where $\Psi_t$ is the angular position of the sun as given by the local time.

For $\Phi_N = \Phi_N'$, the amplitude of variation is the largest possible because the telescope then points the direction of maximum anisotropy.

In fig. 2 $\Psi'_E$ is plotted as a function of momentum in the range 15—40 GeV Z/c. The values of $\Psi_t$ are given by Malmfors' telescope measurements in Stockholm 1948.

Assuming that there is only one direction of excess intensity we can determine its angle as well as the momentum of the important part of excess radiation by means of the points of intersection between the three curves in fig. 2. The momentum appears to be about 20 GeV Z/c.

The three curves should intersect in one point, but particles in the zenith direction have not passed the same atmospheric layer as particles in the north and south directions, and therefore they could have been influenced in an other way. Moreover the error in the deter-

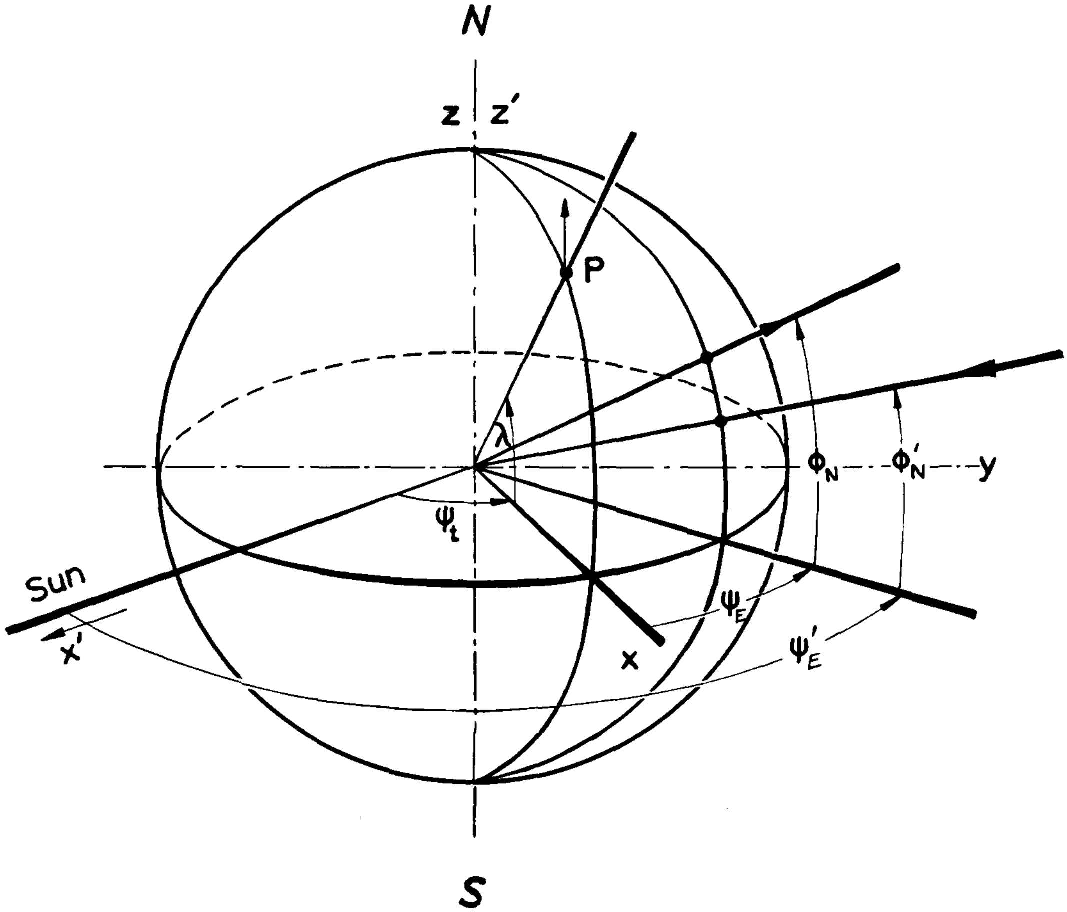


Fig. 1. The definition of the angles $\psi_E$, $\Phi_N$, $\psi'_E$, $\Phi'_N$ and $\psi_t$.

mination of the time of maximum is about half an hour which means an error in the curves of $\pm$ 7°. It must be pointed out that the curves do not intersect in any other point in the momentum range $10^{10} \rightarrow \infty$ eV Z/c.

A second method to determine the momentum is the following:

Consider two counter telescopes which measure the intensity in east and west directions respectively. Each of them registers a diurnal variation. Maxima of the cosmic ray intensity do not occur simultaneously for both telescopes but in general with a time interval of $h$ hours due to the deflection in the magnetic field of the earth. For any particular momentum this interval can be plotted by the curves of Brunberg and Dattner as a function of zenith angle and latitude.

Fig. 3 shows 6 diagrams for different values of primary momenta. Each diagram gives $\Delta\Psi$ as a function of latitude, where $\Delta\Psi = h \cdot 15°$ (The earth rotates 15°/hour). The curves marked 8°, 16°.... etc. correspond to zenith angles of 8°, 16°.... etc. for the two telescopes, one directed east of zenith, the other west of zenith. The curves in fig. 3 are plotted from the diagrams by Brunberg and Dattner.

Concerning fig. 3 a few noteworthy properties should be pointed out. For the lowest momenta the curves begin at $\lambda = 30°$ and higher latitudes, because the corresponding particle orbits are either forbidden or so close to the forbidden cones that an experimental determination was impossible.

At the geomagnetic pole ($\lambda = 90°$) the limit of $\Delta\Psi$ for all zenith angles and all momenta is

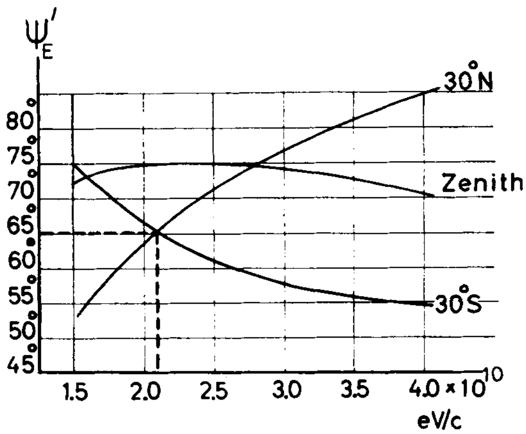


Fig. 2. The direction of anisotropy $\psi'_E$ in the equatorial plane as a function of momentum. Particles arrive in the zenith direction and in directions which form an angle of 30° with the zenith. $\lambda = 58°$.

+ 180° or − 180° which is natural because the orbits arriving at the magnetic pole are symmetric in relation to the magnetic axis.

For low latitudes $\Delta\Psi$ is positive. That means that the maximum measured in east direction occurs before the maximum in west direction. This is typical for all momenta in this momentum range and can easily be seen in a simple model of two particle orbits arriving from east and west on the equator. However, a study of fig. 3 shows that the phase difference gets smaller for higher latitudes and $\lambda = 50°$ is a critical point for momenta below 30 GeV Z/c. On latitudes higher than 50°, $\Delta\Psi$ becomes negative for lower but not for higher momenta. This property gives a possibility to determine which part of the primary momentum spectrum gives the largest contribution to the measured intensity, and relevant observational data might give interesting results.

In other words for low primary momenta maximum in west direction should occur before maximum in the east direction for latitudes over 50° ($\Delta\Psi$ negative) and vice versa for latitudes between 0° − 50°. But on the other hand maximum should occur in east before west at all latitudes for momenta above 30 GeV Z/c.

Measurements of the diurnal variation in east-west directions in Manchester (Elliot and Dolbear 1951) indicate that maximum in the east direction comes before maximum in the west direction. Thus maximum in east direction occurs at 14*h* and in west direction at 16*h*. According to the analysis of fig. 3. the momentum appears to be more than 30 GeV Z/c.

These results, viz. the analysis of fig. 2 and fig. 3 seem to indicate that the main contribution to the variation considered comes from momenta in the region 20—40 GeV Z/c. In the following we shall assume that the whole variation is caused by particles in this momentum range and make a computation both for 20 and 40 GeV Z/c. It is possible that the maximum of the momentum distribution is rather flat so that we have to integrate over the measuring cone of the telescope for different momenta in order to find out the direction of anisotropy.

## The phase angle of the diurnal variation

The analysis of the recorded data of the radiation gathered during the last 20 years gives a possibility to determine the phase angle and amplitude of the diurnal variation.

The apparatus used were Geiger-Müller telescopes and ionization chambers.

Values taken from recording stations with Geiger-Müller telescopes are rather easy to correct and the trajectories can be followed back to infinity by the curves of Brunberg and Dattner, because the telescopes measure in a cone well defined by the geometric arrangement. Ionization chambers, however, are not directional to the same extent, but owing to atmospheric absorption particles arriving in the zenith direction contribute more to the total intensity registered than particles arriving from other directions.

A fairly good correction for the influence of the geomagnetic field can be obtained also for an ionization chamber if the trajectories of particles hitting the chamber are followed backwards to infinity. The atmospheric absorption must then be included, for instance by the approximation that the intensity is reduced as $\cos^2 z$ where $z$ is the zenith angle. (Cf. Montgomery, Cosmic Physics, p. 169.)

This has been done in the following way. The sky at the place of observation is divided into 36 regions bordered by the circles with zenith distance $z_n = n \times 10°$ ($n = 0, 1, \ldots 9$) and azimuth $a = 45°, 135°, 225°, 315°$. Each of these regions is given a weight proportional

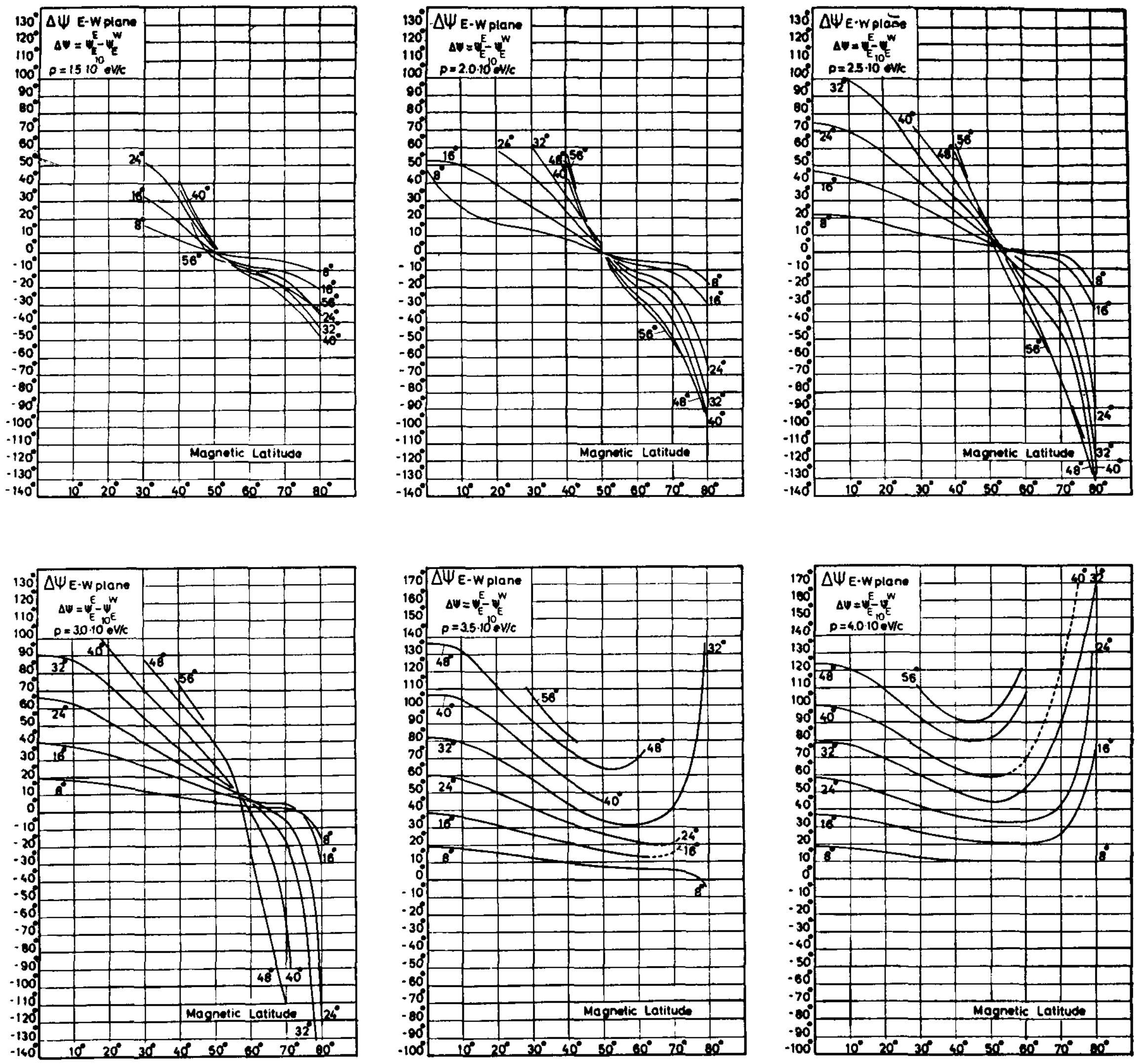


Fig. 3. $\Delta\psi$ as a function of magnetic latitude.

to $\cos^2 z_m \cdot \sin z_m$, where $z_m = (n + \frac{1}{2})$ 10°. The first factor $\cos^2 z_m$ takes into account the diminishing sensitivity of the ionization chamber with increasing zenith distance, the second factor $\sin z_m$ the variation of the size of the regions with zenith distance.

A histogram is then prepared for the regions in each of the four main directions N, E, S, W. Let us take an example. Mark along the abscissa axis of the histogram for the north direction the deflections $\Psi_E$ corresponding to $z_n = n \cdot 10°$ along the northern meridian. Above each interval between these marks we then draw a rectangle with area equal to the weight $\cos^2 z_m \cdot \sin z_m$ of the corresponding region in the sky. We finally add the four curves obtained in this way for the directions N, E, S, and W, and the position of the maximum in this final curve gives a definite direction of maximum sensitivity in the equatorial plane outside the earth's magnetic field. A complete correction should have included a

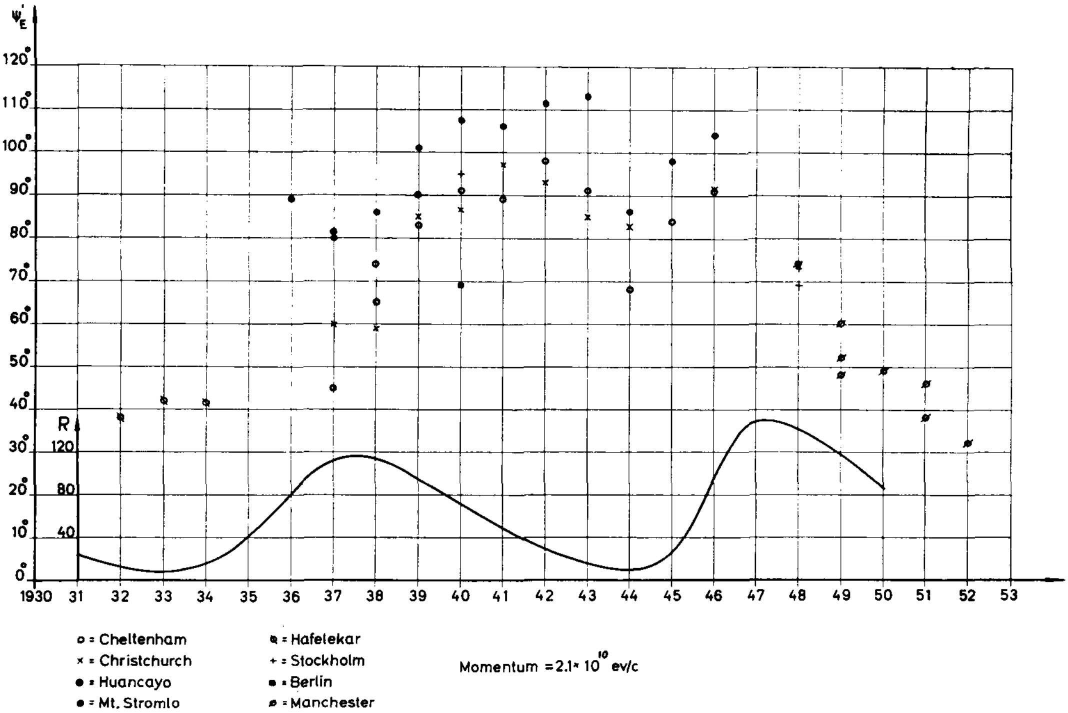


Fig. 4. The direction of anisotropy as a function of time. R is the Zürich sunspot number.

similar study of $\Phi_N$, but as for the moment we are only interested in $\Psi_E$, it has not yet been done. This may include an error, but an inspection of the appearance of the $\Phi_N$-diagrams in the chosen momentum range (BRUNBERG-DATTNER, 1953) shows that the error is of no importance in this case.

ELLIOT and THAMBYAHPILLAI (1953) have published a diagram of the phase of the diurnal variation as a function of time over a period of 20 years, and it is very interesting that there appears to be a systematic change in phase over the years.

Fig. 4 shows ELLIOT'S and THAMBYAHPILLAI'S diagram when the correction has been app ied for the deflection in the geomagnetic field. Momentum is supposed to be 21 GeV Z/c. a value taken from fig. 2.

The most interesting result is that the diurnal variation seems to be due to an excess of particles arriving from the 18 *h* direction, although there are some fluctuations about this direction.

An example of these fluctuations is given in another form by SARABHAI and KANE (1953), who point out a correlation between the phase and amplitude of the diurnal variation and the sunspot activity, during the period 1938 – 45.

It may be physically significant to divide the diurnal variation into two components, one tangential component, arriving from the 18 *h* direction and another radial component, arriving from the 12 *h* direction. In the following we shall explain the tangential component by means of the rotation of the solar magnetic field.

## Theory of the diurnal variation

JÁNOSSY (1937) suggested that the solar magnetic field which he supposed to be a dipole field, cuts off the low energy part of the cosmic ray spectrum. This theory, which has been developed by VALLARTA (1937) and EPSTEIN (1938), indicated that a diurnal variation might possibly be produced by this effect, and the maximum should occur at 18 *h*. In spite of the fact that the corrected experimental results indicate that the maximum occurs at this time, the theory is not acceptable in its original form. It has been shown by ALFVÉN (1950) that already the scattering by the terrestrial magnetic field is enough to fill up the forbidden orbits in the solar magnetic field in such a way that no diurnal variation is produced. This has been confirmed by investigations by KANE, SHANLEY, and WHEELER (1949).

## Diurnal variation produced by the solar *rotation*

Suppose that near the solar surface we have a magnetic field of such a shape that charged particles are trapped in it. Due to the inhomogenity of the solar field $\left(\frac{\partial B}{\partial r} \neq 0\right)$ charged particles even at cosmic ray energies move in trochoids around the sun.

After some time the distribution of these particles will be isotropic in a coordinate system which is at rest in relation to the sun.

In a fixed coordinate system which does not take part in the solar rotation, the isotropic distribution will be anisotropic due to the solar rotation. This obviously holds close to the solar surface, for example in the magnetic field produced by a sunspot. It is also likely that it holds good high up in the corona but far from the sun it does not. Charged particles which are trapped for example near the orbit of Neptune will certainly tend to be isotropic in a coordinate system fixed in the galaxy. The question is where the limit goes between the regions where charged particles are isotropic in relation to a fixed coordinate system and the region in which they are isotropic in relation to a system which takes part in the solar rotation.

Before we discuss the problem it is of interest to point out that the anisotropy of particles close to the sun could be explained as an effect of the solar electric field. Seen from a fixed coordinate system, the rotating sun is strongly polarized so that the voltage difference between the poles and the equator is of the order of $10^9$ volts. In the equatorial plane the electric field is radial and determined by

$$E_r = \omega \cdot r \cdot B \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where $\omega$ = angular velocity of the sun
$r$ = distance to the sun
$B$ = magnetic field strength at the distance $r$.

When a charged particle moves in a homogeneous magnetic field, its path is a circle. If an electric field $E$ is introduced perpendicular to the magnetic field, the circle drifts with the velocity

$$v = \frac{E}{B} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

and the path of the particle is a trochoid. Inserting $E_r = \omega r B$ from eq. (1), the drift velocity seen from a fixed coordinate system is found to be

$$v = \frac{E_r}{B} = \omega \cdot r \quad \ldots\ldots\ldots \quad (3)$$

i. e. particles follow the sun in its rotation. This is not valid for too large values of $r$, as discussed below.

Thus the combined action of the electric field from this polarization and the solar magnetic field will cause an anisotropy in relation to a fixed coordinate system.

Seen in this way our question is, how far out from the sun the solar electric field is strong enough to affect the cosmic radiation. In order that cosmic rays at a certain distance take part in the solar rotation the following two conditions must be satisfied.

1) There must be magnetic lines of force running from the volume element in question directly to the sun. If this is the case Ferraro's theorem shows that in average the ionized matter in this element must rotate with the same angular velocity as the sun.

2) The radius of curvature of the cosmic ray in the magnetic field must not be too large. If a cosmic particle has a very high momentum so that it passes almost rectilinearly through the magnetic field the effect of an electric field will be small. On the other hand if the radius of curvature is so small that the particles move in trochoids, the solar rotation is transferred to the cosmic radiation via the electric field $E_r$. Without an elaborate calculation it is difficult to decide exactly at what momentum this transition takes place, but it is likely that it occurs at a momentum which is of the order of magnitude of the momentum of a particle which moves in a circle around the sun. The momentum of this particle depends on the strength of the solar magnetic field. For this effect the value of the solar magnetic field at the earth's orbit is of decisive importance.
Although the value is still not definite it seems reasonable that the strength of the solar

magnetic field is of the order of 10 gauss (ALFVÉN 1950, 1952). If no disturbance occurs outside the sun, this field should decrease as a dipole field. At the orbit of the earth the value of the field would the be $10^{-6}$ gauss. In this field a particle moves in a circle with a radius of curvature equal to the earth's orbit, if its momentum is 5 GeV $Z/c$.

Usually the solar magnetic field is disturbed very much. There is no doubt that solar activity especially solar flares and the presence of big sunspots, causes emission of streams from the sun which produce magnetic storms and auroras when they reach the earth. There are good reasons to believe that these streams consist of neutral ionized gas. The conductivity is certainly very high so we should expect that the magnetic lines of force are "frozen into" the volume of the gas which is sent out in the beam. This means that the conductivity of the gas in the beam is so large that any motion of the matter relative to the magnetic field lines would be retarded due to strong induced electric currents in the gas. We confine ourselves to a discussion of the phenomena near the equatorial plane.

Consider a volume element near the sun (fig. 5). The surface of this element parallel to the equatorial plane is

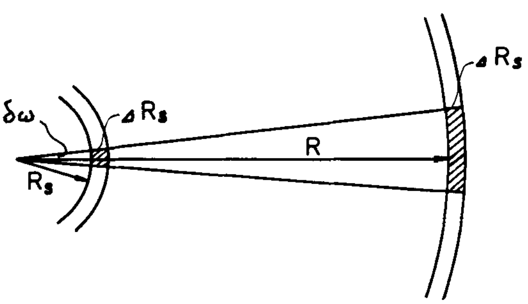


Fig. 5. A volyme element of matter is transported outwards from the sun.

$$\Delta R_S \cdot \delta\omega \cdot R_S \ldots\ldots\ldots\ldots \quad (4)$$

and the magnetic field strength

$$H_S = \frac{\Phi}{\Delta R_S \cdot R_S \cdot \delta_\omega} \ldots\ldots\ldots \quad (5)$$

where $\Phi$ is the flux through the element. If the element is emitted radially, it will expand and its area is

$$\Delta R_S \cdot \delta\omega \cdot R \ldots\ldots\ldots\ldots \quad (6)$$

at a distance $R$ from the sun. The magnetic field strength in it is now

$$H = \frac{\Phi}{\Delta R_S \cdot R \cdot \delta_\omega} = H_S \cdot \frac{R_S}{R} \ldots\ldots \quad (7)$$

or less.

Hence in a beam $H$ is proportional to $1/R$. Even if several beams are active at the same time, we could not expect the solar magnetic field in average to decrease as slowly as $1/R$. However, in order to discuss two extreme cases we shall discuss this case and the dipole case. In order to treat the case when $H$ decreases as $1/R$ we must put an outer limit to the field. We tentatively put this to twice the earth's orbit. Thus

1)

$$H = \text{const} \cdot \frac{1}{R^3}$$

$$H_E = \frac{10}{200^3} \approx 10^{-6} \text{ gauss}$$ (At the orbital radius of the earth)

$$H_E \cdot \delta = H_E \cdot 1.5 \cdot 10^{13} = 1.5 \cdot 10^7$$

$$p = 300 \cdot 1.5 \cdot 10^7 \approx 5 \text{ GeV } Z/c$$

where $p$ is the momentum of a particle, moving in a circle around the sun at the orbital radius.

2)

$$H = \text{const} \cdot \frac{R_S}{R}$$

$$\varphi = \int_{R_S}^{2R_{S-E}} \text{const.} \cdot \frac{R_S}{R} \cdot 2\pi R \cdot dR \approx 10 \cdot \pi R^2$$

where $R_S$ radius of the sun

$R_{S-E}$ = orbital radius of the earth

This gives

$$\text{const } \frac{10}{4} \cdot \frac{R_S}{R} = \frac{2.5}{200}$$

$$H_E = \frac{2.5}{200} \cdot \frac{7 \cdot 10^{10}}{1.5 \cdot 10^{13}} = 5.8 \cdot 10^{-5} \text{ gauss}$$

$$H_E \cdot \delta = H_E \cdot 1.5 \cdot 10^{13} = 0.89 \cdot 10^9$$

$$p = 300 \cdot 0.87 \cdot 10^9 = 260 \text{ GeV } Z/c$$

As the momentum which gives the diurnal variation is of the order of 30 GeV Z/c we find that this is intermediate between the two cases which we have discussed. Hence in some cases, especially when there is a strong solar activity so that the solar magnetic field is much disturbed, we should expect the cosmic radiation we measure to take part in the solar rotation. In other cases when the disturbances are small we should expect only a fraction of the radiation spectrum to take part in the rotation. If cosmic radiation takes part in the solar rotation completely, we should expect an anisotropy of the radiation so that we receive more radiation at 18*h*. Further the energy of the particles which reach the earth at the afternoonside will be higher and this also causes an increase in the measured intensity. Actually the whole phenomenon is of the same type as the Compton-Getting effect.

COMPTON and GETTING (1935) showed that if cosmic radiation originates outside our galaxy we should expect a diurnal variation with sidereal time. This is due to the fact that the solar system is moving with a velocity of 300 km/sec toward declination 47° N and right ascension 20 h 40 min. owing to the rotation of the galaxy. If cosmic radiation is isotropic in inter-galactic space we should measure a greater intensity on that side of the earth facing the direction of motion.

The application of this effect discussed in the present paper was suggested to the authors by H. Alfvén.

Suppose the cosmic radiation in the neighbourhood of the earth takes part in the solar rotation with the same angular velocity as the sun, the velocity relative to the earth is

$$v = \frac{2\pi \cdot R_E}{T} = 4.0 \cdot 10^7 \text{ cm/sec} = 0.13 \cdot 10^{-2} \cdot c$$

where $T$ = synodic rotation period of the sun = 27 days

$R_E$ = orbital radius of the earth

$c$ = velocity of light.

This gives us a possibility to calculate the expected excess of particles on the afternoonside of the earth.

According to COMPTON and GETTING (1935) the number of particles, $n'$, impinging on a surface moving with velocity $\beta \cdot c$, is given by the ratio

$$n'/n = 1/(1-\beta\cos\omega')^3 \;\ldots\ldots\; (8)$$

where $c$ = velocity of light

$\beta < 1$

$n$ = number of particles impinging on the surface at rest

$\omega'$ = angle between the velocity vector of the moving surface and the direction of a moving particle, with a speed almost equal to that of light.

VALLARTA, GRAEF, and KUSAKA (1939) have improved the calculations of Compton and Getting by taking into an account the deflection of cosmic particles in the magnetic field of the earth under the assumption of the primary energy distribution functions

$$f(E) = \text{const. } E^{-3} \text{ or } f(E) = e^{-KE}$$

In order to show the expected amplitude of diurnal variation due to a solar rotation a similar computation has been carried out below. However, although the primary spectrum is fairly well known, we do not know how the yield function varies with energy for the secondaries observed at sea level. In order to find an upper and a lower limit for this expected amplitude we shall deal with three cases:

1) Primaries having only one momentum and a velocity almost equal to that of light.

From equation (8) we get

$$n'/n \approx (1+\beta\cos\omega')^3 = 1 + 0.39 \cdot 10^{-2} \ldots \; (9)$$

for $\omega' = 0$ and $\beta = 0.13 \cdot 10^{-2}$

Thus the amplitude of the diurnal variation, measured within a narrow solid angle with a counter telescope on the equator above the atmosphere, should be 0.39 %.

2) Primaries having an energy distribution function

$$f(E) = \text{const. } E^{-3}$$

Vallarta, Graef and Kusaka show that the fractional variation in intensity is

$$\frac{n'-n}{n} = 12\beta \cdot r_0^4 \int \cos\omega' \cdot \frac{dr}{r^5} \;\ldots\; (10)$$

where $r$ is in Störmer units

$$r_{\text{Störmer}} = 4.1 \cdot 10^{-6}\sqrt{V}$$

In fig. 6 the earth is seen from the north pole. Equation (10) is solved graphically for a few values of $\omega$ with $r_0 = 0.5$ Störmer, corresponding to the lowest particle momentum in the zenith direction. The maximum amplitude should be about 0.27 % and the maximum occurs at 12.30 *h*.

From this it appears that with a distributed spectrum the effect is smoothed out to some extent.

3) Primaries which have the same energy distribution but the integral is now taken from $r = 0.6$ Störmer up to $r = 0.8$ Störmer.

This gives a maximum of 0.36 % at 13.30 *h*.

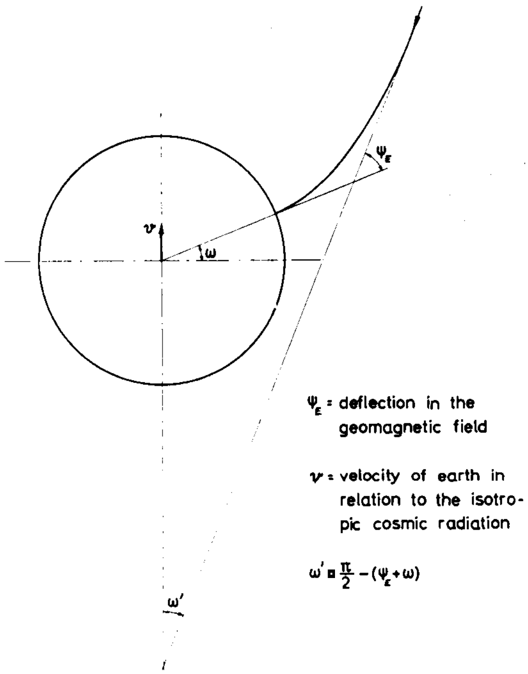


Fig. 6. The orbit of a cosmic ray particle in the equatorial plane of the earth.

All these values were calculated without taking into account the fact that a motion of the earth in relation to the isotropic cosmic radiation alters not only the number but also the energy of the particles observed. This may even increase the amplitude calculated above.

From this follows that if the radiation takes part in the solar rotation completely, we should expect a diurnal variation at the equator with an amplitude between 0.4 % – 0.3 % when measuring with a narrow counter telescope.

Some observers measure an amplitude of the diurnal variation of about 0.2 %. The difference between the calculated and measured values may be due to three causes.

The first of them is the possibility that the cosmic radiation only to some extent takes part in the solar rotation.

Secondly the angular resolution of cosmic ray instrument is limited. Counter telescopes have solid angles of $0.1\pi - 0.5\pi$ and ionization chambers $2\pi$.

Finally, as shown in the comments to fig. 1, p. 75 the amplitude is a function of $\Phi_N - \Phi'_N$ and thus will be smaller than the calculated value if $\Phi_N \neq \Phi'_N$.

The secular variation of the phase, as shown by Elliot and Thambyahpillai's curves, indicates that there are also other factors influencing the diurnal variation. As will be discussed in a coming paper by Alfvén (Tellus 1954. In course of publication), changes in the solar magnetic field influence cosmic radiation inside the earth's orbit in such a way that when cosmic ray generation is strong, more cosmic radiation will diffuse outwards from the sun and thus alter the phase of diurnal variation.

We whish to point out that a computation of the expected amplitude of the diurnal variation can now be carried out in other latitudes than the equator by means of the curves of Brunberg and Dattner. Perhaps the discrepances between registrations of diurnal variation measured in different latitudes can at least to some extent be explained in this way.

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