On the Interpretation of Ionization in the Lower Ionosphere Occurring on Both Day and Night Side of the Earth within a Few Hours after some Solar Flares

By BENGT HULTQVIST, Kiruna Geophysical Observatory, Sweden

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Abstract

Some strong solar flares cause very strong absorption in high geomagnetic latitudes on both day and night sides of the earth. The absorption effect is measurable a few hours after the solar flare outbreak. It is shown that the effect can be interpreted as being caused by a high-energy-ion beam of very small density, emitted from the sun and moving in Störmer orbits.

Large ionospheric absorption effect following a solar flare outburst within a few hours without giving rise to any geomagnetic or auroral effects was reported for the first time from many ionospheric observatories north of 60° geomagnetic latitude after the big solar flare of 23 February 1956 (cf. SHAPLEY and ROBERTS, 1957).

Since the end of March 1958 a riometer (Relative Ionospheric Opacity Meter) designed by C. G. LITTLE at Geophysical Institute, College, Alaska (concerning construction and operation *vide* LITTLE and LEINBACH, 1958) has been in operation at Kiruna Geophysical Observatory. That apparatus records the cosmic noise vertical flux on 27.6 Mc/s. Relative values of the total absorption in the whole ionosphere can be obtained if the absorption is supposed to be zero on days with very high recorded cosmic noise influx (that the absorption is very small on such days will be shown below).

During the period of operation three solar flares followed by heavy ionospheric absorption (peak value > 15 db) have been observed, namely on 7 July, 16 August and 26 August 1958. The effects of the former flare on several upper atmosphere parameters as observed at Kiruna Geophysical Observatory have been reported (HULTQVIST, AARONS and ORTNER, 1959).

In spite of the small number of observed flare effects a preliminary report will be given here and an interpretation will be proposed. The latter might be considered as a working hypothesis until it has been confronted by more complete observational material. Due to the rarity of the phenomena and the declining solar cycle we will perhaps have to wait for a long time for such statistical data.

Description of the absorption observations

The outbursts of the solar flares of importance 2 + and 3 + respectively of 7 July, which with all probability were responsible for the absorption, occurred at 0030 and 0040 U.T., fairly near the center of the sun's disk. On 7 July the sun was circumpolar in Kiruna (geographical coordinates 67.8° N, 20.4° E;

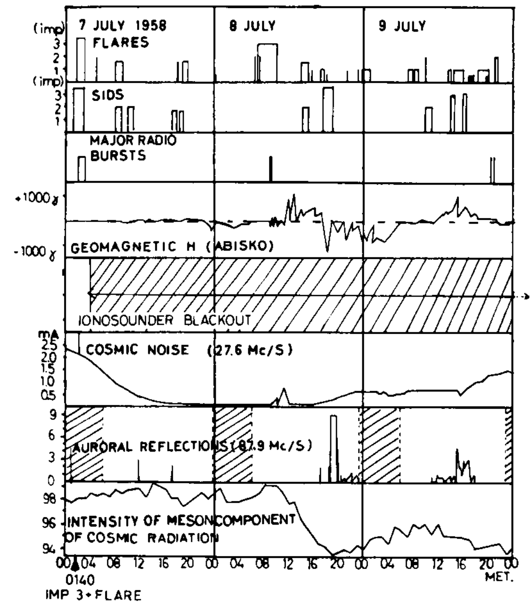

Fig. 1.

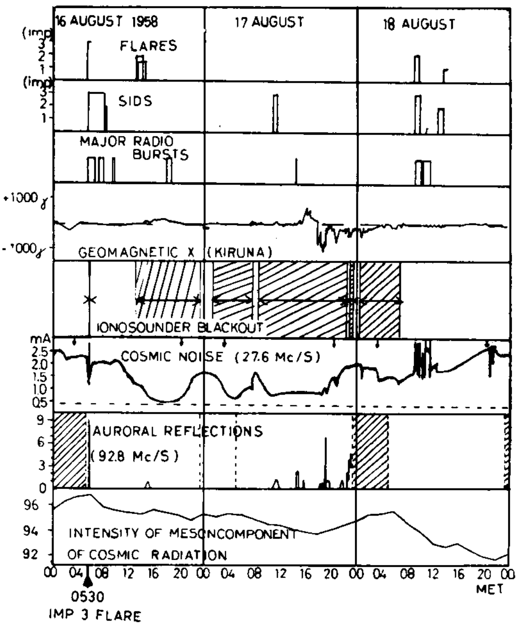

Fig. 2.

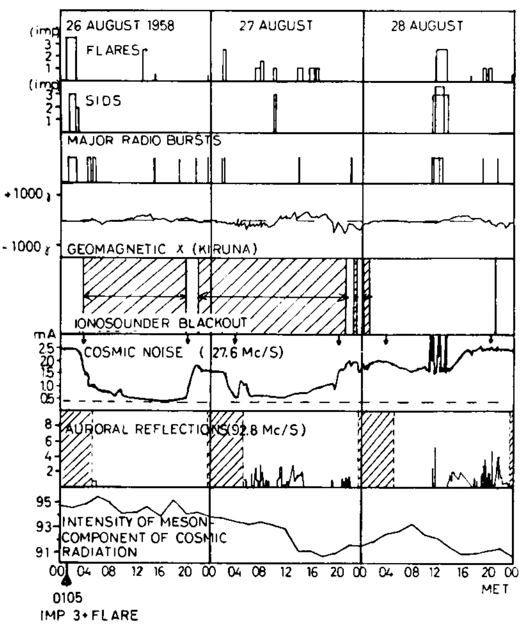

Fig. 3.

geomagnetic coordinates 65.3° N, 115.5° E). At the time of the flare outbursts the elevation angle was 3.4 degrees. Kiruna was, however, at the same time on the night side geomagnetically.

Figs. 1—3. Collocation of information on solar flares, SIDs and major radio noise bursts and records of the five parameters geomagnetic horizontal component, blackout periods for the ionosounder, 27.6 Mc/s cosmic noise power, oblique auroral reflections on 87.9 and 92.8 Mc/s respectively, and the meson component of cosmic radiation for the three periods 7—9 July, 16—18 August and 26—28 August 1958 respectively. The small arrows above the cosmic noise curve indicate the time of sunset and sunrise in Kiruna at the earth's surface.

On 16th of August an importance 3 flare was observed to start at 0430 U.T., the location on sun being 13° S, 49° W, at which time Kiruna was on the sunlit hemisphere. Finally an importance 3 + flare outbreak followed by a very strong SID (importance 3 +) was observed at 0005 U.T. on 26 August 1958, at which time it was night in Kiruna.

About two hours after the flares on 7 July and 26 August and approximately four hours after that of 16 August a slow decrease in incoming cosmic noise signal began to be visible on the riometer record.

The variation of absorption with time for the three periods being considered in this report can be seen from Figs. 1—6. Figs. 1—3 gives a schematic collocation of data, collected at Kiruna, for several parameters interconnected with the ionospheric absorption. The values of Figs. 4—6 have been reduced from the origi-

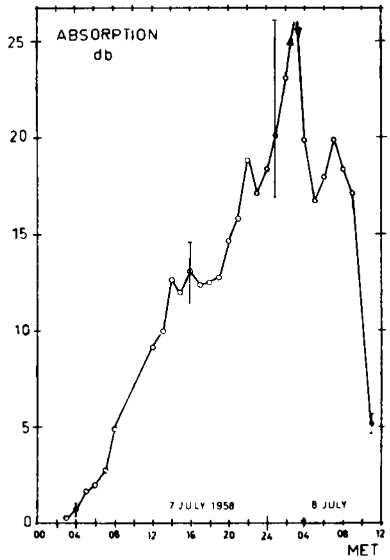

Fig. 4.

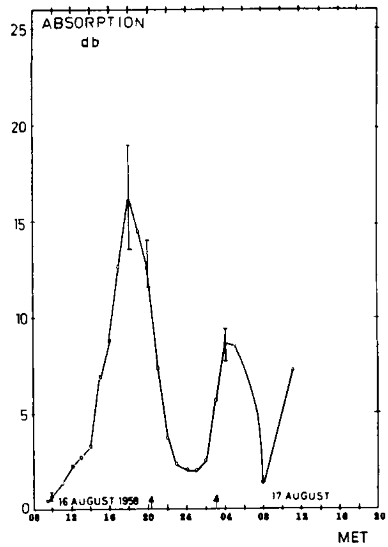

Fig. 5.

Figs. 4—6. Absorption as a function of time for the three periods 7—9 July, 16—18 August and 26—28 August 1958 respectively. The maximum limits of errors due to reading of the record are given for a few points to indicate the order of magnitude. The uncertainty in the relative position of neighbouring points is far less.

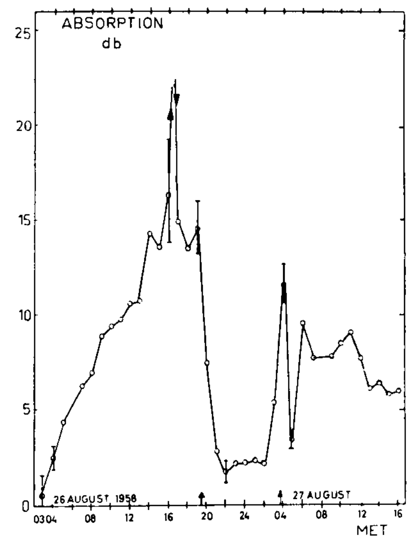

Fig. 6.

nal Easterline-Angus records for every hour. During the night between 7 and 8 July and in the afternoons of 16 August and 26 August the absorption reached its maximum, amounting to more than 20 db (the signal strength was so near zero that only a lower limit can be stated with any certainty), 16 db and more than 20 db respectively.[1] As far as we are aware these peak values are the highest absorption values reported for vertical radiation around 30 Mc/s. For instance, LITTLE and LEINBACH (1958) found a day time absorption peak value of about 8 db after the solar flare of 23 February 1956, and a corresponding night time value of 1.8 db for 30 Mc/s cosmic noise. CHAPMAN and LITTLE (1957) report that the peak value of the absorption in College (geomagn. lat. 64.5° N) "may reach or even exceed 10 db by day and 5 db by night".

As Kiruna had midnight sun during the first absorption period no decrease of absorption during the night was observed. During the August periods, however, very marked night time decreases (down to about 2 db) can be seen from Figs. 2, 3, 5, 6 and 7. That effect can be attributed to solar control of an electron detachment process in the ionosphere (cf. e.g. CHAPMAN and LITTLE, 1957; BAILEY, 1957; HULTQVIST, 1959).

During the first hours of the magnetic storms on the days after the flares the absorption decreased to 5.2, 1.3 and 3.5 db respectively

[1] The group at Sodankylä, Finland, measured 27 db absorption on 7 July (DIEMINGER 1958, private communication).

for the three periods in chronological order, and then increased again.

About 24 hours after the flares a slow decrease (the diurnal variation not taken into account) of absorption began. The decrease was, however, often interrupted by periods of low increase (Figs. 1 and 6). The increases and the short time changes of the curve can in most cases be attributed to special events as aurora, magnetic storm effects etc. Slow increases (such as those during the night between 8 and 9 July) must be attributed to an ionizing agent or possibly drift motion.

In spite of what was said above about irregularities in the curve during the strong absorption period the smoothness of the riometer curve is much more remarkable. A comparison between the first and last days of Fig. 1 gives an idea of that. This indicates that the ionization is homogeneous over a very large area, in contrast to the ionization caused by aurora.

The most remarkable feature of the whole phenomena is, however, the absense of currents (except such causing quiet day magnetic variations) in the ionosphere (Figs. 1—3) before the sudden commencement (which was observed also after the flare on 23 February 1956; cf. SHAPLEY and ROBERTS, 1957).

Only observatories above 60 degrees geomagnetic latitude observed absorption effects on the night side after the flare of 23 February 1956 (SHAPLEY and ROBERTS, 1957). For the three flares discussed here similar restriction to geomagnetic latitudes greater than 60° has been found. In all cases the Swedish ionospheric observatory at Lycksele (geomagn. lat. 62.5° N) observed long duration blackouts but the duration was shorter than in Kiruna. At Uppsala Ionospheric Observatory (geomagn. lat. 58.4° N) no blackout was observed during any of the periods of interest.

Review of hypothesis for the night-time ionization of the D-layer

Based on observations made by VAN ALLEN and his coworkers (*vide* MEREDITH et al., 1955) CHAPMAN and LITTLE (1957) have proposed as explanation of the low altitude ionization in connection with aurora, that bremsstrahlung photons emitted by some thousandth of incoming electrons in the usual auroral heights

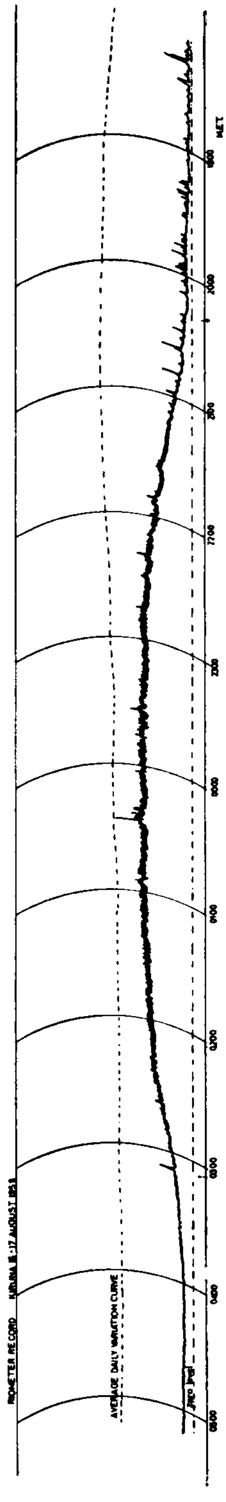

Fig. 7. Increase of the cosmic noise signal strength during night hours. Arrows indicate sunrise and sunset at the earth's surface.

is the ionizing agent for the lowest ionosphere. That mechanism may very well be operating in connection with aurora, but there seems to be some important difficulties in adopting it to the solar effect discussed here, namely that the large absorption observed makes it necessary to assume a fairly large number density of electrons in the incoming beam, which seems difficult to combine with the total lack of geomagnetic and auroral effects.

That the ionization in the D-layer is caused by fairly high energy ions coming from the large solar flares, in cases of the kind being discussed in this report, has been proposed by Bailey (1957) and Ehmert and Revellio (1957). In his comprehensive article Bailey has discussed the problem in detail. There seem, however, to be some difficulties left, the most important one being that his adopted ion masses and energies would, with all probability, make the effect detectable far below 60° N geomagnetic latitude. He has also neglected the ionization of the primary ions in his calculations, which ionization seems to be very important (cf. below).

Analysis of the phenomena and outline of a mechanism for ionization of the D-layer

Velocity of particles:

The possibility of determining the velocity of the particles giving rise to the absorption is fairly poor. From the riometer record we have to determine when a decay in signal strength that is not of daily variation type starts. The daily variation sometimes changes significantly within a week or so, as the cosmic noise temperature in the antenna beam, moving over the sky, changes, which increases the difficulty.

The technique adopted is to construct an average daily curve from undisturbed days within one or two weeks before the flare outburst of interest. The uncertainty in the time interval between the flare outburst and the beginning of decline of cosmic noise power reaching the antenna is estimated to be not more than an hour. The determination of such a "travel time" for the solar particles does not rule out the possibility of existence of much faster particles in the beam, which, however, must be too few to cause measurable absorption.

The travel times determined correspond to specific rectilinear velocity values. If the trajectories of the particles were Störmer orbits in a dipole field the measured travel times would correspond to slightly higher velocity values for the rigidities in question (see below). The magnetic field in interplanetary space is, however, certainly far from a dipole field. The sun's magnetic field may vary from time to time due to distortions caused by solar flares (Alfvén, 1956). This and possible irregular distribution of interplanetary matter having a magnetic field makes it probable that the interplanetary magnetic field is irregular. That means that the trajectories of particles of a low density beam (cf. below) may be much longer than the rectilinear distance. This is the fact for instance with the interplanetary field proposed by Alfvén (1956) (cf. Block, 1958 a). As far as the author is aware it is, however, impossible to give any quantitative relations based on observational data.

For the event of 7 July a travel time of about two hours could be extracted from the record. On 16 and 26 August the corresponding values were four hours and two hours respectively.

After the solar flare that occurred at 0331 U.T. on 23 February 1956 effects in the lower ionosphere on the earth's night side were observed within 20 minutes after the flare outburst (*vide* e.g. Bailey, 1957; Ehmert and Revellio, 1957).

Conclusions from effects of the earth's magnetic field on the particle orbits:

The fact that in all cases discussed above the effects were restricted to higher geomagnetic latitudes than approximately 60 degrees indicates that if particles originating in the sun are assumed to cause the ionization these corpuscles must be charged.

If the number density of the beam is supposed to be very small (arguments for that will be given below) then the particle orbits are Störmer orbits. From the velocity (unknown; only "travel time" can be measured) and the upper geomagnetic colatitude limit (Θ) reached by the particles, a lower limit of the heaviest mass number present in the beam can be obtained from the relation

$$\sin \Theta = 0.01202\ (H\varrho)^{1/4} \qquad (1)$$

Table 1. Mass number of particles reaching the latitude limit

Lower geomagnetic latitude limit	Time interval between the flare outburst and observed start of absorption effect		
	20 min.	2 hours	4 hours
60°	2 (H—He)	13.1 (C—N)	26.3 (Mg—Al)
62°	1.6 (H—He)	10.3 (Be—B)	20.7 (Ne—Na)

(where $H\varrho$ is the rigidity of the particles; STÖRMER, 1955, p. 296) with sufficient accuracy for the rigidity values of interest. Reasons why only a lower limit of the heaviest mass number present in the beam can be obtained for a given velocity value will be discussed below.

All solar flare effects observed in the summer of 1958 had about the same geographical extent, as mentioned above. The lower geomagnetic latitude limit was somewhere between 62.5° (Lycksele) and 58.4° (Uppsala). For two different limit latitudes, namely 62° and 60° the mass number of the ions reaching the latitude, rectilinear trajectories being presumed, is given in Table 1 for the solar flares being discussed (time intervals between flare outbursts and observed start of absorption effect 2, 4 and 2 hours respectively) and also for a "travel time" of only 20 minutes, which should correspond approximately to the flare effect of 23 February 1956.

As can be seen from the table the mass number which must, for postulated rectilinear orbits, be attributed to those corpuscles reaching the lowest latitudes differs very much between the four cases of flares, and in all cases it is lower than 40 (for calcium), which BAILEY (1957) has generally claimed to be the ionizing agent. Thus calcium ions would reach lower latitudes than 60 degrees even if they had the lower limit velocity, corresponding to rectilinear orbits.

Depth of penetration of the particles:

BAILEY (1957) has worked out a very valuable diagram (copied in Fig. 8) that gives a good survey of the relations between velocity, mass number, lower geomagnetic latitude limit and penetration depths. The penetration depths for the heavier ions, which are theoretical, might, according to BAILEY (1957), be fairly much overestimated due to the neglect of stripping effects. The diagram might be used for a discussion of the effect, keeping in mind that numerical statements are fairly unsure.

For the travel time range of interest the penetration depth (D) can be written

$$D = mv \cdot F(v) \qquad (2)$$

(m is the particle mass and v the velocity) where $F(v)$ is a function only of v and not of m for the particles.

Discussion of the reason why strong absorption effects are not observable below about 60° geomagnetic latitude:

Let us for the moment assume that the mass spectrum of the beam emitted from the sun is fairly broad. The lower geomagnetic latitude limit is a function only of the momentum for equally charged particles (cf. (1)). If the penetration depth were also a pure momentum function (that means $F(v)$ in (2) was a function of mv instead of v, which is equivalent to the "equal penetration depth lines" in Fig. 8 being parallel to the latitude lines) strong absorption could be observed in those latitudes where the corresponding penetration depth was suitable, and only in those latitudes, irrespective of the velocity of the beam.

That the particles should not penetrate too far into the atmosphere is due to the fact that for very high electron collision frequencies (ν) the absorption coefficient for HF radio waves is inversely proportional to ν. This is discussed below.

If we postulate a broad mass spectrum of the beam, the primary condition that must be fullfilled is that the penetration depth must be suitable. Suppose the limits of the suitable range are 60 and 85 km. We see that latitudes lower than 60° geomagnetically are reached only for very restricted values of velocity and mass number. For very fast beams (several tenths of the light velocity) no strong absorption would be observed, because the penetra-

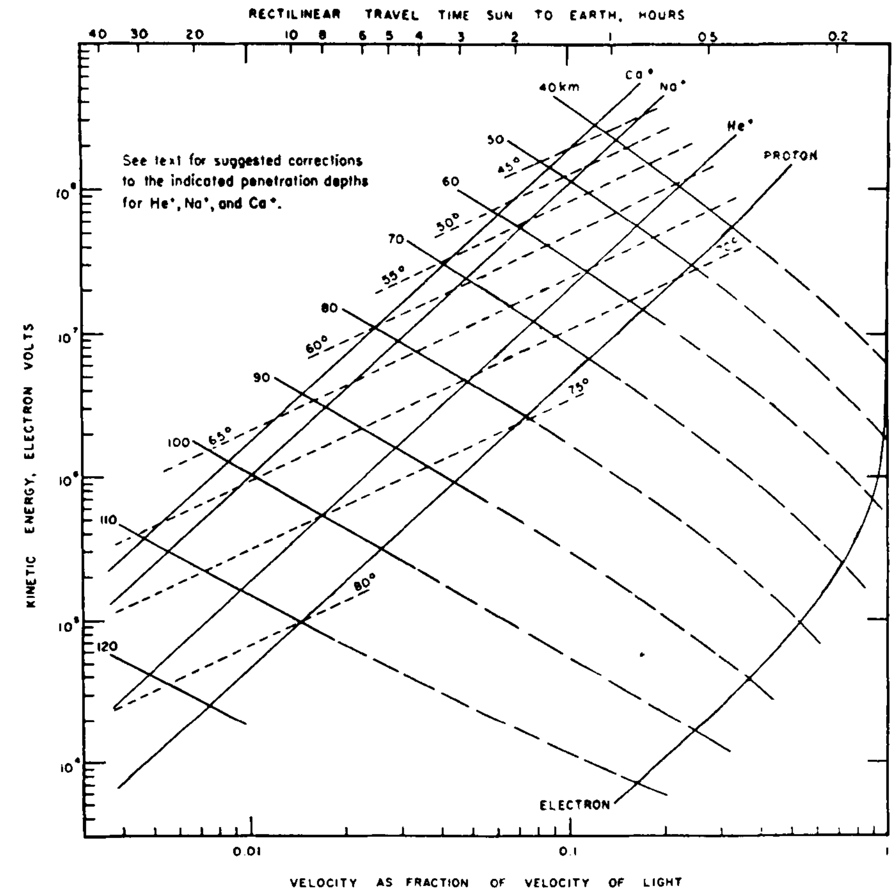

Fig. 8. Diagram showing the connections between rectilinear travel time sun to earth, velocity, kinetic energy, atmospheric depths of vertical penetration, lower geomagnetic latitude limit for singly charged particles, and kind of charged particle (After BAILEY, 1957).

tion depth would be too great for the whole mass spectrum of the beam. However, the velocity spectrum of the beam may perhaps be fairly broad and there will also be some interaction between the beam particles and the atmospheric layers far above the height where the particles are stopped. Even particles, which do not reach the D-layer but the lower E-layer, may produce measurable absorption. We should therefore not expect very distinctive limits.

Against the dominating role of heavy ions in the beam is the fact that the cosmic abundance of such ions is very small (less than one per mille), 91 % of the atoms being protons and 9 % helium atoms (ALLEN, 1955).

There are two difficulties for the hypothesis that protons are responsible for the absorption in and to the south of the auroral zone. One is that a high velocity of 0.5 c is required for them to reach even 65 degrees geomagnetic latitude. Such a velocity corresponds to a rectilinear travel time of approximately 20 minutes. In order to reach the earth not earlier than two and four hours after the start the length of the proton trajectories must be 6 and 12 times the rectilinear distance respectively. For 60 degrees geomagnetic latitude the corresponding figures are about 10 and 20 times.[1] The other difficulty is that protons with such velocities will penetrate the atmosphere to depths far

[1] Of course permanent ring currents around the earth, storage of magnetic clouds in the vicinity of the earth etc. may decrease the lower geomagnetic latitude limit but that will not be discussed here as no quantitative results are available as far as the author is aware.

below 40 km altitude, which means that only a small amount of their energy will give rise to absorption-producing electrons in suitable heights. The penetration depths for protons given in BAILEY's diagram (Fig. 8) presume vertical rectilinear orbits in the atmosphere. The curvature of the orbits and scattering in the latter part of the penetration path, where the velocity has decreased appreciably, and also an existing small angle with the vertical direction will decrease the penetration depth a little. Such a correction of the proton curve of Fig. 8, however, will certainly not amount to more than some 10 km, which is not enough to make the protons stop in the lower D-layer.

However, protons in large enough amounts would give the observed absorption and there would also be a gradual decrease in absorption with decreasing geomagnetic latitude, due to the increasing penetration depths of the protons, as has been observed. The needed increase in number density compared to an equivalent flux stopping just below the D-layer can be estimated from the "stopping cross section" (SEGRE, 1953). In order to produce the same ionization per cm in the upper layers there must be some 100 times more protons of 200 MeV than of 1 MeV and about 10 times as many as of 15 MeV energy. For constant proton flux (number density of the beam inversely proportional to the velocity) the absorption effect would increase rapidly with increasing latitude. Postulating protons, the lower geomagnetic latitude limit would thus be due to the fact that even if there are protons of energy enough for reaching a lower latitude, interaction with the atmosphere would occur too deep within. For all flare effects discussed in this report the lower latitude limit has been the same which means that the upper limit of the proton energy spectrum must have been a few hundred MeV. It seems probable but is not necessary according to the interpretation given that flare effects of the type described here are more common inside the auroral zone. A detailed study of the effect at high latitudes may give information that can throw some light on the problem if the ionizing particles are protons or heavier ions.

For helium ions all problems discussed above for protons will be reduced considerably. It seems probable that helium ions are responsible for a significant fraction of the absorption effect, because of the more favourable geographic distribution and penetration depth and their relatively high abundance in the solar surface layers. This assumption is supported by the discovery of helium lines in the auroral spectrum (GALPERIN, 1958).

The fact that the absorption in connection with the high energy flare of 23 February 1958 was much lower than the absorption effects observed during the summer of 1958 fits into the picture.

Estimation of necessary number density of the beam:

The absorption is given by

$$A = -20 \log_{10} \frac{E}{E_0} = \frac{20}{\ln 10} \int k ds \qquad (3)$$

where A is the absorption in db;
E_0 is the incoming field strength without attenuation;
E is the attenuated field strength;
k is the absorption coefficient,

the integral being taken over the path of the radiation.

For Kiruna's geomagnetic latitude and 27.6 Mc/s vertical radiation the propagation is quasilongitudinal.

For that case k can be written

$$k = \frac{p}{2c} \frac{\beta}{(\alpha \mp |\gamma_L|)^2 + \beta^2} \qquad (4)$$

where p is the angular frequency of the radiation;

$\alpha = -p^2/p_0^2$;
$p_0^2 = 4\pi N e^2/m$;
$\beta = p\nu/p_0^2$;
$\gamma_L = p p_L/p_0^2$;
$p_L = H_L e/mc$;
H_L = the component of the earth's magnetic field along the propagation path;
ν = collision frequency for the electrons;
N = electron number density;
e and m refer to the electron and
c is the velocity of light.
— is for the ordinary ray and
+ is for the extraordinary one.

For the case of interest the values of the absorption coefficient are for the ordinary ray

Table 2. Normal electron density (N cm^{-3}), electron collision frequency (ν sec^{-1}), and apparent recombination coefficient (γ cm^3 sec^{-1}) as functions of height

Height km	65	70	75	80	85	90	95	100	105	110	115
N	10	$1.5 \cdot 10^2$	$1.6 \cdot 10^2$	$5 \cdot 10^2$	$1.5 \cdot 10^4$	10^4	$4 \cdot 10^4$	10^5	$1.3 \cdot 10^5$	$1.6 \cdot 10^5$	$2 \cdot 10^5$
ν	$3.5 \cdot 10^7$	$2 \cdot 10^7$	$9 \cdot 10^6$	$4 \cdot 10^6$	$1.5 \cdot 10^6$	$6 \cdot 10^5$	$2.2 \cdot 10^5$	10^5	$5.5 \cdot 10^4$	$2.5 \cdot 10^4$	$1.4 \cdot 10^4$
γ	$5 \cdot 10^{-6}$	$0.8 \cdot 10^{-6}$	$2.5 \cdot 10^{-7}$	$1.3 \cdot 10^{-7}$	$0.8 \cdot 10^{-7}$	$5 \cdot 10^{-8}$	$4 \cdot 10^{-8}$	$3 \cdot 10^{-8}$	$2.8 \cdot 10^{-8}$	$2.5 \cdot 10^{-8}$	$2.3 \cdot 10^{-8}$

$$k_0 = \frac{0.0529}{3.20 \cdot 10^{16} + \nu^2} \nu N \text{ cm}^{-1} \qquad (5)$$

and for the extraordinary ray

$$k_e = \frac{0.0529}{2.60 \cdot 10^{16} + \nu^2} \nu N \text{ cm}^{-1} \qquad (6)$$

Table 2 contains values of N for the normal case, ν and γ (the apparent recombination coefficient). The values of N for the normal case are those given by WAYNICK (1957). The apparent recombination coefficient has been obtained from MITRA and JONES (1954), whose values have arbitrarily been reduced somewhat to make them better adaptable to both day and night conditions (cf. WAYNICK, 1957). The collision frequency values are taken from NICOLET (1953).

With the values of Table 2 the normal absorption is found to be 0.5 db. To this should be added the absorption in the F-layers, which in any case is less than the given value.

The term ν^2 in (5) and (6) can be neglected down to 65 km. For that altitude the error introduced by neglecting this term will be only 4 %. For heights where the values of ν are greater than 10^8 the absorption decays rapidly with decreasing height. From extrapolation of NICOLET's (1953) curves the ν-value can be estimated to be attributable to a height between 50 and 60 km.

If we assume that the ionization causing absorption is distributed in a parabolic layer with $N=0$ for $h=60$ km and the peak value at a height of 85 km (which coincides with the normal peak height, *vide* Table 2)[1] a numerical integration gives, for the peak electron number density corresponding to an absorption of 23 db, the value $8 \cdot 10^4$ cm^{-3}. The number density distribution with height is given in Fig. 9 together with the normal case of Table 2. The E-layer has arbitrarily been supposed to be unaffected.

Taking into account the extraordinary ray reduces the value by some 7 %, and the effect of the broad beam of the antenna is supposed to make the number too large by less than 10 %.

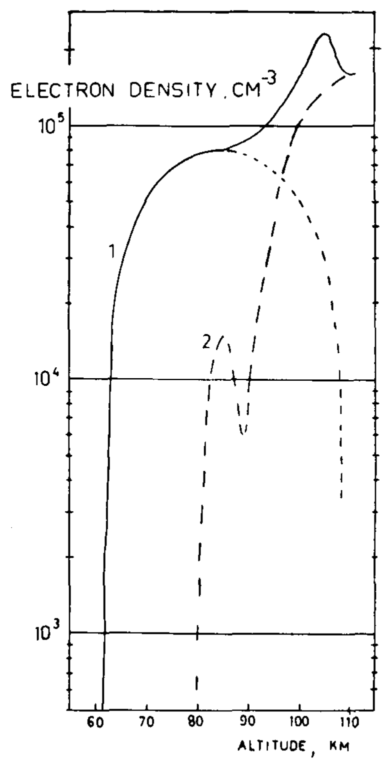

Fig. 9. Distribution of electron density (cm^{-3}) with altitude (1) in a parabolic layer with a peak height of 85 km and zero density at 60 km causing a nondeviative absorption of 23 db for 27.6 Mc/s vertical radiation (solid line) and (2) in an average D layer (according to WAYNICK, 1957).

[1] For other height distributions the corresponding electron number density will be different. As the real height of the absorbing layer is unknown, it has been presumed that the peak height has the normal D-layer value.

Table 3. Electron productions giving rise to the two electron distributions of Fig. 9 as functions of height

Height km	65	70	75	80	85	90	95	100	105
electr./cm^3 sec flare case	$4.2 \cdot 10^3$	$2.1 \cdot 10^3$	$1.1 \cdot 10^3$	$7.7 \cdot 10^2$	$5.1 \cdot 10^2$	$3.0 \cdot 10^2$	$1.8 \cdot 10^2$	77	23
normal case	$5 \cdot 10^{-4}$	$1.8 \cdot 10^{-2}$	$6.4 \cdot 10^{-3}$	$3.3 \cdot 10^{-2}$	18	5	0.45	$3.0 \cdot 10^{-2}$	$4.8 \cdot 10^{-2}$

Using the apparent recombination coefficient of Table 2 we find the values presented in Table 3 for the electron production per cm^3 and second, q, for the given altitudes.

The values of Table 3 have been obtained from the relation $q = \gamma N^2$, which gives the "effective" electron production. This is equal to the total electron production only if the electron number density, N, is much greater than the negative ion number density, N^-, and if dN/dt is much less than $q/(1+\lambda)$ and $\gamma N^2 (\lambda = N^-/N)$, that means in the stationary case. During the rapid increase of the absorption the electron production was 3.5 times as high as the stationary value. An average value of N, weighted with the electron collision frequency (ν), is found to correspond to a height of 68.5 km for the electron distribution of Fig. 9. With the average number of N, 1.4 10^4 cm^{-3}, the ν-value corresponding to the same height ($2.5 \cdot 10^7$ sec^{-1}), the average value for the ion-ion recombination coefficient ($3 \cdot 10^{-11}$ cm^3 sec^{-1}) obtained from the riometer records (cf. HULTQVIST, 1959) and a λ-value of 50 (reasonable for the 68 km level; *vide* HULTQVIST, 1959) a stationary state value for the electron production (q) of 15 electrons/cm^3 sec was obtained. During the rapid increase of absorption the q-value was found to be 52 electrons/cm^3 sec. That means that in a column with one cm^2 area $2.3 \cdot 10^8$ electrons per second are produced in the flare case.

For mass numbers and velocity values of particles causing absorption down towards 60 degrees geomagnetic latitude under the conditions postulated above the energy varies between roughly 10 MeV and 300 MeV. If the energy for production of one electron-ion pair is taken as 40 eV (which is certainly not too low) we can see that one ion produces between $3 \cdot 10^5$ and $5 \cdot 10^6$ electrons. In case of the strongest absorption effects an influx of 50—1,000 ions/cm^2 sec is required to produce the absorption. The corresponding velocities vary between 0.03 c and 0.4 c, approximately, as deduced from the rectilinear travel time. If only protons and helium ions are supposed to be effective the velocity figures, deduced from the lower geomagnetic latitude limit, vary between approximately 0.2 and 0.7 c.

The effective number density of the beam moving with the velocities mentioned must thus be within $5 \cdot 10^{-9}$ to $1 \cdot 10^{-6}$ cm^{-3}, if heavy ions are assumed and between $2 \cdot 10^{-9}$ and $2 \cdot 10^{-7}$ cm^{-3} if protons and helium ions are the ionizing agents.

In the discussion here only the ions effective in the atmosphere have been considered hitherto. It has already been pointed out that protons will penetrate to great depths in the atmosphere. As has also been mentioned before this fact means that we have to increase the density by a factor not greater than 100 and probably of the order of 10, to take into account the energy release to layers giving negligible radio wave absorption.

The ions of the beam are focused towards the poles of the earth which means an increase in density compared to the conditions far from the earth. On the other hand the majority of the ion trajectories in the vicinity of the earth do not reach the atmosphere, which counteracts the focusing effect. Due to lack of quantitative information, the counteraction is supposed to be exact.

If on the other hand moderately heavy ions is the effective agent we must assume that they are accompanied by protons which reach the ionosphere much nearer the poles. If not very selective emission mechanisms are operating the total beam density must be higher than the density of the effective ions by at least a factor 1,000.

The densities mentioned above are extremely small values compared to those which are thought to exist in beams causing aurora and magnetic storms. CHAPMAN (1950) and FER-

RARO have estimated the minimum density of a neutral ionized gas sufficient to produce a moderate magnetic storm at 100 electron-ion pairs and MARTYN (1951) has given a corresponding value of 20. CHAPMAN (1950) has stated that a density of far below one ion per cm^3 is necessary for application of STÖRMER's theory. According to the electric field theory the number density of a beam giving rise to a magnetic storm is roughly 0.1 electron-ion pair per cm^3 (BLOCK, 1958). Whichever of the named values of number density in magnetic-storm-producing beams is adopted, we see that the values for the beam discussed above are less by several powers of ten.

Thus the existence of the observed intense ionization without any currents seems reasonable.

The linear increase of absorption during the first hours is a natural feature of the interpretation given (cf. HULTQVIST, 1959), as is the observed maximum in effect during the night between 7 and 8 July when the sun was over the horizon, and at the same time the higher corpuscular flux on the geomagnetic night side was acting.

The decrease of absorption during the first few hours after the sudden commencement of the geomagnetic storm:

In the three observed cases of the effect under discussion a very marked decrease of absorption occurred after the sudden commencement (Figs. 1—6). This indicates that the interactions of the two beams (the first causing absorption only, the second causing magnetic disturbances) with the ionosphere are different.

It is a well known experimental fact that the F2-layer very often in the polar regions is quite destroyed at the start of a magnetic storm (RAWER, 1953). That the F-layers were strongly affected by the dense beam is supported by the fact that the F-echoes returned at lower total absorption (as measured by the riometer) than they disappeared at. It was also observed after the flare of 7 July 1958 that the F-echo heights were usually about 100 km higher at the echo's return after blackouts than when the blackouts began (cf. HULTQVIST, AARONS and ORTNER, 1959).

The most simple explanation for the decrease of the absorption seems to be that the ionization is removed from the height region, where its absorption effect is maximal, either by a vertical electric field or by thermal effects (heating and expansion) caused by the magnetic storm producing beam.

The increase of absorption following the transient decrease may be attributed to the geomagnetically active beam, and if protons are ionizers in the high energy beam, perhaps also to a gradual expansion of the lower electron-rich regions of the ionosphere up into levels of higher absorption.

Discussion

The interpretation presented above gives a possible explanation of the similarity in effect irrespective of the difference in beam velocity, the geographical extension, the total absence of any magnetic effects, and the gradual increase of the absorption during the first hours after the flare outburst.

As given above there may be two slightly differing ways of interpreting the effect. One postulates a broad mass spectrum of the beam and velocities of the ions differing only slightly from those corresponding to rectilinear travel time. The other is based on the presumption that the ionization in the lowest ionosphere is caused by protons and helium ions of high velocity, in which case either irregular trajectories in the interplanetary space, of lengths about one order of magnitude larger than the rectilinear distance sun to earth, which trajectories also must differ from time to time, must be assumed, or a profound influence of ring currents and magnetic clouds near the earth on the ion orbits must exist. None of these alternatives seems to be highly improbable.

It seems probable that the corpuscular radiation producing the effects discussed in this report is identical with that one deduced from radio observations of the sun by WILD, ROBERTS and MURRAY (1954).

The basic feature of the absorption effect, namely the lack of magnetic deviations in spite of the dense ionization, seems to be understandable with any of the alternatives of the hypothesis that solar ions moving in Störmer orbits are the agent.

The experimental bases—three absorption periods—is of course very meagre and more thorough investigation of a greater number is highly desirable. It will be carried out as soon as a larger observational material has been obtained. Due to the rarity of the phenomena this might take several years.

Measurement of the absorption by means of riometers at as many points as possible differing in geomagnetic latitude by only a few degrees from 55° towards higher values would probably give information that would tell us, which of the proposed alternatives of mechanism (if any) is operating.

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