in electrostatic distribution deduced by Mange and there is a layer of helium ions between the layer of atomic oxygen ions and the layer of atomic hydrogen ions. In other words, neutral and ionized helium play a leading rôle between 100 km and 3000 km.

The vertical distribution of the electron concentration above the F_2 peak must be interpreted as indicating that helium ions predominate after atomic oxygen ions and before protons. A consideration of the effects of magnetic storms on the ionosphere should include the presence of helium. The following table shows (in round figures) the various concentrations for a temperature of the order of 1600°K.

	500 km	1000	3000	5000	25000
O^+	10^5 cm^{-3}	10^4	10^2		
He^+	10^3	10^4	10^3	5×10^2	
H^+	10^1-10^2	$<10^3$	10^3	10^3	10^2
ν_e	100 sec^{-1}	10		1	10^{-1}

Since the electron collision frequency is not less than 1 sec^{-1} for heights below 5000 km and the symmetrical charge transfer $(X^+)_a+(X)_b \rightarrow (X^+)_b+(X)_a$ is not less than 10^{-9} cm^3 sec^{-1}, the vertical distribution of ions in the earth's magnetic field should be based on conditions in which collisions play a rôle. Thus, during magnetic storm conditions, the nature of the ions should be considered when the electron concentration varies. An increase of the temperature in the lower F_2 region increases the number of neutral molecules which leads to an increase of the recombination coefficient since the ion interchange rate coefficient must increase. In the exosphere, a decrease of the electron content should be considered with a possibility of escape of ions.

References

1) Symposium d'Aéronomie, Communications présentées à la réunion de Copenhague (Juillet 1960), IAGA Symposium n° 1, International Association of Geomagnetism and Aeronomy, 238 pages, 1961 (Extraits des Annales de Géophysique, Tome 17 n° 1, 2 et 3, 1961).
2) M. Nicolet: Aeronomy in Handbuch der Physik (Geophysik)—Band XLIX to be published, Springer Verlag, Berlin-Göttingen-Heidelberg, 1961.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-I, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-6-P2. Disturbances in Ionospheric Regions

W. J. G. BEYNON

Department of Physics, University College of Wales
Aberystwyth, Wales, U. K.

Introduction

At this plenary session I have been asked to present a summary of the main events in the earlier sessions on polar disturbances and in those on ionospheric disturbances.

Nearly all discussions of the ionospheric disturbances in this conference have been concerned with the results of ground based radio studies, and consequently they refer to that part of the ionosphere below the peak of the $F2$ layer. None of the discussions have dealt with the upper side of the ionosphere, and indeed most of the papers have been concerned with the phenomena at the lower end at the D layer heights or with perturbations in the peak $F2$ electron density. Storm phenomena are to be found at all levels in the ionosphere, but they are most obvious in the D and $F2$ layers. It is however worth noting that the study of small but significant perturbations in the middle and lower part of the ionosphere, especially at the upper part of the region E, may well be profitable, since these levels are now believed to be those where the important dynamo currents flow.

Review of 'Polar Ionospheric Disturbances'

It has long been recognized that the polar ionosphere is very sensitive to magnetic disturbance, and in 1932–33, on the occasion of the Second Polar Year, the polar blackout phenomenon was independently discovered by the British expedition at Tromsö and by the Soviet workers at Murmansk. It was then referred to as the "no echo" condition, and was associated with intense magnetic activity. The Soviet paper of thirty years ago describing the phenomenon states that "it is as if a screen was placed between the ground and the ionosphere, so that no signals could get through to the reflecting layer". This is now described as the intense ionization at the *D* layer heights. The British workers at Tromsö also made a special study of the 'auroral *E* phenomenon'. They noted that it was night-time in occurrence and clearly associated with mild magnetic activity. In place of the "night-time auroral *E* phenomenon" we now talk about "sporadic *E* on the dark side of the polar zone".

Radio wave absorption phenomena can now be studied by at least four different methods. Three of these, *—fmin* measurements, long-wave reflections, and VHF forward scatter, measure unambiguously the ionization changes underneath the *E* layer. The fourth method, the riometer (relative ionospheric opacity meter) measures an integrated absorption effect extending through the whole ionosphere from top to bottom. Although it is fairly certain that major absorption occurs in many cases at *D* region heights, this is by no means always the case, and appreciable absorption sometimes takes place during transmission through the *F*2 region.

Studies of polar ionospheric conditions, made especially during IGY by these four methods, have shown that the radio wave absorption phenomena resulting from *D*-region ionization can be divided into two main categories. One is accompanied by magnetic disturbance and the aurora, and exists along and near the auroral zone. This type of absorption is very variable in time duration and in space, it can last for periods of minutes or hours, and the lower latitude boundary of this zone of strong *D*-layer absorption, like that of the auroral zone itself, may shift equatorwards as the main phase of the magnetic storm develops. The other high-latitude absorption phenomenon consists in ionospheric absorption over a wide area *within* the polar cap. It can exist without simultaneous magnetic disturbance, and is often established some hours in advance of the commencement of a magnetic storm. This is the polar cap absorption, the so called the 'PCA' phenomenon.

Characteristics of the PCA Phenomenon

From the results presented at this conference, the following picture of the PCA phenomenon emerges.

i) PCA results from an additional production of ionization at levels in the height range 45 to 75 km.

ii) The extra ionization is there before the onset of a magnetic storm, and it would appear that there can be this ionization over the polar cap without any magnetic storm.

iii) PCA may be confined to the polar cap above geomagnetic latitude 60° or 65° in its first stages, but during the main phase of an ensuing magnetic storms the spatial extent of the extra ionization spreads to lower latitudes, and occasionally reaches geomagnetic latitude 50°. This observed shifting to lower latitudes is closely related to the growth of the *Dst*-field of the magnetic storm.

iv) The phenomenon can endure for several days, but it exhibits a pronounced variation with solar illumination in that the area over which it occurs seems to be much more extended on the daylight side of the polar cap.

v) Studies of IGY arctic and antarctic data show that PCA occurs over both polar caps, but the time of commencement in the two hemispheres may differ and sometimes the time of commencement varies with both latitude and longitude.

vi) The phenomenon shows a clear solar cycle variation, there being a maximum occurrence in 1957–58, and an absence of the phenomenon in the years of last sunspot minimum.

vii) PCA is associated with a solar flare and its duration appears to vary with the position of the flare on the sun.

viii) If a sudden commencement magnetic storm occurs when the PCA is already in progress, then at high latitudes at least, there appears to be an actual reduction in the ionization density at this D region level.

Balloon and rocket observations at the time of PCA show that the phenomenon is due to the influx of protons emitted at the time of intense solar flares. The analysis of the incidence of the phenomenon over the past ten years shows that many more PCAs are recorded than solar cosmic-ray events on the ground, but all cases of the latter were followed by the polar cap absorption within an hour or so. The marked daylight bias in the spatial extent of a PCA event may perhaps be explained in terms of the loss of electrons from the absorbing region at night by an attachment loss process with photo-detachment by solar radiation occurring in the morning. However the negative ion concerned with this process has not yet been identified.

Absorption in Lower Latitudes

The observation that during a PCA event at high latitudes a sudden commencement magnetic storm *reduces* the ionospheric absorption, is to be considered along with another experimental fact described at this meeting viz., that riometer absorption measurements at a low latitude station also show a reduced attenuation of incoming radio signals on the day following a sudden commencement magnetic storm. The authors attribute the reduced absorption, not to a reduction in the D layer ionoization, but to the well-known storm reduction in F layer ionization. It is clear that more information is required on the ionospheric absorption changes during sudden commencement magnetic storms which occur at the time of PCA, before any adequate explanation can be offered for these observations.

We have also heard of at least two examples of a D-layer disturbance (observed in some temperate latitude long-wave radio propagation studies) which started on the day following the sudden commencement of a magnetic storm and continued for no less than 6 or 7 days after the magnetic conditions, and the disturbed $F2$ layer, had returned to normal. The dates of these two observations did not appear to coincide with the occurrence of polar cap disturbances, although this point needs to be carefully checked. Here again the maintainance of intense ionization below 85 km at 50° N for six days after the magnetic condition had returned to normal, presents an interesting problem. The author hinted at two possible alternatives; one that the electrons are being lost by night by attachment and released again during day by solar radiation, and the other that the phenomenon possibly represents 'dumping' of particles from the outer radiation belt during and after magnetic storms.

Spiral Pattern in Polar Blackout and Sporadic E

A feature of many recent studies of ionospheric disturbance phenomena in polar latitudes has been the evidence for spiral-like or curved precipitation patterns for the two main polar ionospheric phenomena — polar blackouts and polar sporadic E. (It does not appear to have been established with certainty yet that the patterns are definitely spiral in form or merely curved.) The latitude variations in the former exhibit a sort of spiral pattern on the morning side of the pole, and for sporadic E a differently directed spiral pattern on the evening side of the geomagnetic pole is found. The original simple interpretation in terms of particles of opposite sign, conveniently identified by protons and electrons, is no longer believed to be valid, and a much more complex mechanism which involves convective and rotational motion in a portion of the magnetosphere has been suggested.

$F2$ Disturbance over the World during Magnetic Storms

We turn now to a brief consideration of region $F2$ during a magnetic storm. The *average* behaviour of $F2$ during the storm is now well established and may be summarized as follows.

i) At high latitudes, including the auroral zone, a marked depression of $F2$ electron density occurs with the maximum effect centred on noon. The depression is different in different seasons; in summer $foF2$ is depressed over the whole 24 hours, whereas in winter it is depressed for several hours centred about noon.

ii) At low latitudes, including the equator, an increase is observed in every season, and a depression is rather rare.

iii) At middle latitudes there may be a depression or an increase of the electron density depending upon the latitude of the station and upon season.

It is emphasized that these represent the *average* behaviour based on conditions for many storms, and sometimes there are significant departures from this general picture.

To complete the average picture one other experimental fact must be added, namely

iv) During an intense storm a depression of $fF2$ occurs all over the world.

Vertical Drift Motion of Electrons

In 1953 Martyn suggested that in any explanation for the main features of the effect of a geomagnetic storm on the $F2$ layer, vertical drift motion of electrons would be an important, if not a dominant, factor. He suggested that this drift would be produced by the *SD* electric field, which is established in the auroral zone interacting with the permanent magnetic field of the earth. The theory was later notably developed by a group of Japanese workers, Maeda, Hirono and Sato. In a series of papers Sato applied this drift theory to explain the ionospheric storm condition in region $F2$ for equatorial, temperate and auroral latitudes. The vertical drift velocity is a function of strength and inclination of the magnetic field and the ionospheric conductivity. On quiet days the drift motion of electrons in the F layer will result from the electric field responsible for the *Sq* current-system, and the field is transmitted from the dynamo region to the F region. But on the magnetically disturbed days the drift motion is the net result of both *Sq* and *SD* effects. Sato has applied this sort of analysis to the observed variation in electron density and height of F layer for a number of individual storms, and has found reasonable agreement between the calculated and the observed variations.

It is also to be expected that the electric current flowing in the ionosphere and interacting with the geomagnetic field would produce some measurable distortion of the ionosphere at the levels at which they flow. Such distortion was discovered by Appleton and Lyon, and independently by Brown and myself some years ago. Its existence has subsequently been confirmed by the work by Shimazaki. The degree of distortion was also examined by Brown and myself for geomagnetically disturbed days, and we have found that the quiet day distortion is quite markedly enhanced in the manner to be expected from the superposition of *Sq* and *SD* current-systems. This result again tends to support the conclusion that the ionospheric storm effects are to be explained in terms of a vertical drift of ionization, and that the net effect on disturbed days is the result of the superposition of quiet-day and disturbed-day currents.

In any consideration of region $F2$ phenomena there is a difficulty which does not exist in the case of the lower D, E, and $F1$ layers. This problem is a fundamental one, viz., why does the $F2$ region have a peak of electron density at all? The D, E and $F1$ regions are closely governed by solar ultraviolet radiation, but from the early days of ionospheric radio sounding and from eclipse observations, it has been recognized that the $F2$ layer shows no such simple solar control. In their analysis of $F2$ layer storm phenomena Maeda and Sato assumed a variation of attachment coefficient with height of a rather arbitrary form but one such that a maximum in electron density would result. The actual variation of the attachment coefficient with height has subsequently been determined by Ratcliffe and his colleagues, and it is quite different from that assumed by Maeda and Sato. In a series of papers Ratcliffe has shown that with this type of height variation of attachment coefficient, the hypothesis originally put forward in 1935 by Bradbury will explain the formation of the peak of the electron density in the $F2$ layer. According to Bradbury's hypothesis, the main level of ion production is at the level of the peak of the $F1$ layer, and the peak in ionization at a higher level is the result of a decrease in loss coefficient with height. It is now clear that the original analysis of Maeda and Sato needs to be repeated in the light of this conclusion concerning the formation of the $F2$ layer, and on the form of the attachment coefficient variation with height. Another objection to the Maeda-Sato's analysis arises from the fact that the true height of the $F2$ layer was not available to them for their work and it seems quite clear that now we need an $F2$ storm analysis, in which the *true* heights are studied. The discrepancy between some of the observed and calculated conditions during a magnetic storm, noted by Maeda and Sato, might then be removed.

IGY antarctic observations have shown that during winter night the electron density in the $F2$ layer can attain very large values indeed, and show a certain regular diurnal variation, although no solar radiation can reach the layer at this time. It would appear that large electromagnetic and tidal forces are important in such circumstances.

Total Electron Content

It is well known that during magnetic storms the peak electron density of the $F2$ layer diminishes in temperate latitudes and increases at low latitudes. It has also been found that the *total* number of electrons in a unit column up to the level of this peak behaves in the same way, i.e. during a storm it decreases in moderate latitudes and increases at equatorial stations. Furthermore recent satellite information on the electron content above the peak suggests that during a magnetic storm the *total* electron content in the whole layer from top to bottom appears to change in the same sense. If this is confirmed, it means that the storm changes do not represent a redistribution of the electrons in the layer, but *real* decreases and increases in the total electron content.

An interesting suggestion has been made in a paper read at this meeting, and one which bears on studies of the $F2$-layer. In this it has been suggested that appreciable fluxes of ionized particles spiral along the magnetic field of the earth to establish an equilibrium condition between the $F2$ layers at magnetic conjugate points in opposite hemispheres. If this suggestion proves correct and if such motion turns out to be an important factor in determining the $F2$ layer peak densities, then theories of the behaviour of region $F2$ under both quiet and storm conditions may certainly need some re-evaluation.

Solar Flare Effects in Region F2

The ionization in the $F2$ layer is often affected by the magnetic storm which follows the solar flare rather than directly by the solar flare itself but occasionally we find that marked increases in the electron density of the region $F2$ are also observed at the time of the solar flare. Such increases in electron density occurred on four out of the eight cases observed prior to November 1960, in which solar flares accompanied by sea-level cosmic-ray increases occurred. This work also indicated that the height of the $F2$ layer at the time of the flare is an important factor in determining whether or not anything happens in the layer. It is suggested that in addition to the emission of high energy particles, these flares were also unusual in their photon radiation, but it is to be emphasized that the possible influence of movement of the layer at such times may be important.

Travelling Disturbances

In one paper, the presence of travelling disturbances have been reported, which appeared to come in at the $F2$ region and move down with velocities of 40–50 m/sec. through the $F2$, $F1$, and E layers, and it was suggested that they may even have produced detectable effects in the D layer. Such travelling disturbances can be readily detected in the ionograms taken in rapid succession on Regular World Days and Special World Intervals during IGY. [In referring to these studies of travelling disturbances which can be made with rapid sequences of ionograms, I think that it is also opportune to give a special word of appreciation to the Worldwide Sounding Committee of URSI under the chairmanship of Mr. Shapley, which expended a very great effort, before and during the IGY, to ensure the highest standard of ionospheric recording and data scaling. The reason that we have already been able to deduce so much from IGY ionospheric soundings is due, in no small measure, to the quiet but effective work of this committee.]

Some Unsolved Problems

In concluding I will list some of the ionospheric phenomena, which seem now to need further study.

In high latitudes we need a satisfactory explanation of the spiral or curved patterns found for blackout and sporadic E ionization, and for the predominant occurrence of one phenomenon on the light side of the pole and for the predominance of the other on the dark side. The relative role of positive and negative particles in these two phenomena is still an open question.

The principal cause of the PCA clearly seems to be solar proton emission, but many detailed features of the phenomenon need further elucidation. Sometimes PCAs are accompanied by magnetic storms and sometimes not. The incidence of PCA is not simultaneous at the north and south polar caps, and there is also evidence for delays in latitude and longitude. Why does the sudden commencement of a magnetic storm during a PCA cause a reduction in ionospheric absorption? Why does the spatial distribution of PCA show a marked bias toward the light side of the polar cap? Further study is necessary of the development of PCAs and their relation to the auroral zone absorption. Are the long period D-region phenomena, those with an after-effect of many days, observed in medium latitudes related to the PCA phenomenon?

For the $F2$-region we need a completely satisfactory explanation for the formation of this region. In such a theory we need to decide the part, if any, which is played by drift from one hemisphere to the other, as has been suggested between magnetically conjugate points. We need to explain the existence of an $F2$ region with a substantial electron content during the long polar winter night, and to explain the regular movements and variations observed at such times. It is necessary to explain why, at temperate latitudes, during a storm the *total* content of the layer is diminished, and why at equatorial latitudes it appears to be increased. In polar latitudes we need to understand the relative influence of particles and electric currents, and to decide what are primary and what are secondary effects. Storm phenomena involving very large increases in the peak electron density of $F2$ need further study.

These are but some of the problems to be solved before we can say that we understand well the storm behaviour in the ionosphere.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-I, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-6-P3. Electric Current in the Ionosphere and the Aurora

Sydney CHAPMAN
Geophysical Institute, University of Alaska
High Altitude Observatory, University of Colorado
Institute of Science and Technology, University of Michigan; U.S.A.

The occurrence of magnetic disturbance indicates the addition of a disturbing field (D) to those normally present, namely to the main field M and the fields Sq and L of the solar and lunar daily magnetic variations. By spherical harmonic analysis or otherwise the D field can be divided into a primary part D_e, of external origin, and the remaining part, $D-D_e$, that is due to currents induced within the earth by the changing field D_e. It is also possible to derive a "conventional" electric current system flowing in a thin concentric spherical surface at some chosen height above the earth, that could produce D_e. The currents that actually cause D_e are not of this kind: they do not flow at any one height above the earth. In the middle belt of the earth the Dst part of D_e is due mainly to two systems of electric current that flow at a few earth radii above the earth's surface. One of these systems (DCF) flows in the surface of the hollow carved by the geo-