Auroral orientation curves and the auroral oval I

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ABSTRACT

A comparison has been made between the auroral orientation curves and the auroral oval determined from the occurrence of the aurora. It has been found that the auroral orientation curve crossing the midnight meridian at 67° corrected geomagnetic latitude is located within the auroral oval. The largest difference between the location of the auroral oval and the 67° curve occurs in the morning hours and it has been argued that the auroral orientation curve gives a better definition of the true auroral oval in this time interval. The auroral orientation curves have also been related to the hydrogen emission and it has been found that the 66° curve of auroral orientation represents the oval of hydrogen emission except in the morning hours, where the data are ambiguous.

Introduction

Since Nikolskii (1947) pointed out explicitly that geomagnetic activity is distributed in the form of a spiral, a number of upper atmospheric phenomena have been reported to appear in spiral patterns. The very extensive data collected during the IGY made it possible to take averages of upper atmospheric data over shorter periods than a day with a reasonable accuracy and it also became possible to investigate the structure of the auroral zone. Oguti (1963), among others, summarized the results of work on spiral patterns. He concluded that most of the spirals would be grouped in two zones. Firstly, the loci of night E-layer, hydrogen emission and broad bay-type geomagnetic disturbances may correspond to precipitation zones of protons in the exosphere, and secondly that loci of a- and f-type Es, ordinary green aurora and sharp negative bays correspond to precipitation zones of electrons. Piddington (1965) studied mainly the results reported on auroral morphology, and he concluded that the particles causing the aurora and associated phenomena could be grouped into three zones. Zone I lies between parallels of geomagnetic latitude 63° and 73° and is related to radio absorption, blackouts X-ray events and mantle aurora. Zone II overlaps Zone I near midnight but extends poleward beyond 80° near noon, and consists of descrete visual aurorae, Es, spread-F, magnetic agitation and H_α. Zone III falls within Zone II and is the region of polar cap aurorae.

In this study the ovals of the instantaneous occurrence of visible aurora and hydrogen emission will be related to the curves based on the orientation of the auroral arcs, as it may be expected that these phenomena are closest related. But from what has been said above the result may have same significance for other upper atmospheric parameters such as sporadic E and bays. It was pointed out by Akasofu & Kimball (1964) that the auroral arcs constitute the basic auroral form with superimposed small scale structures, and that auroral arcs may have a very long east-west extension and follow the instantaneous auroral belt (cf. also Khorosheva, 1962; Feldstein, 1964). Therefore the auroral oval may be expected to be closely related to the orientation curves of the auroral arcs determined by Gustafsson (1967).

It is only during the last few years it has been recognized that the centered dipole approximation of the earth's magnetic field is insufficiently accurate for quantitative analyses of geophysical phenomena which are controlled by the geomagnetic field. Mayaud (1960) and Hakura (1965) made useful world maps based on the calculations made by Hultqvist (1958) of the geomagnetic field lines taking into account the first five spherical harmonic terms of the geomagnetic field. These coordinates are called corrected geomagnetic coordinates by Hakura.

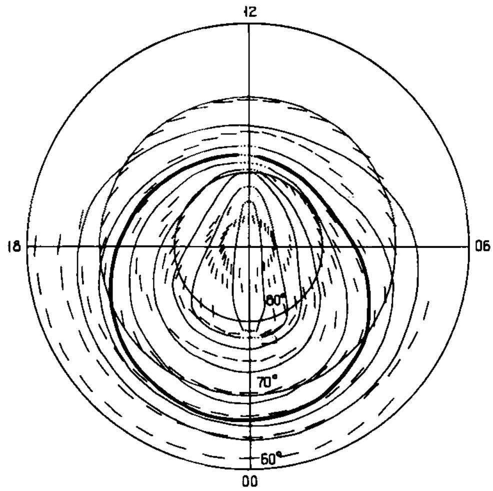

Fig. 1. A polar plot of the auroral orientation curves as a function of corrected geomagnetic time and latitude. The short lines indicate the direction of the auroral arcs.

Cole (1963) made maps of the eccentric dipole system which correspond quite well to the system of corrected geomagnetic coordinates. The difference in latitude is usually less than ± 2 degrees for the stations which have been used and the difference in time between the two systems is less than ± 45 min except for a few degrees of latitude close to the pole.

The auroral orientation curves

Information on the direction of the auroral arcs, mostly based on all-sky camera data during IGY, was collected and organized (cf. Gustafsson, 1967) in a geomagnetic coordinate system, corrected by the higher order spherical harmonic terms. The data from the stations lying at almost the same corrected geomagnetic latitude (regardless of hemisphere) were grouped together giving 9 different latitude groups between the latitudes 61 and 90 degrees. By means of interpolation between the latitude groups, information was gained about the direction of the auroral arcs over a continuous latitude range from 61 to 90 degrees. Integration between the measured values gave the orientation curves of the auroral arcs over the polar region. Fig. 1 shows a polar diagram in corrected geomagnetic latitude and time, in which 8 different orientation curves have been shown. The direction of the auroral arcs for each latitude group has also been indicated for each 40 min interval.

The most striking feature of the auroral curves is that they are all furthest from the pole at midnight (within the range which has been investigated). There is also an asymmetry between 06 hours and 18 hours which amounts to 4 degrees at the latitude of the auroral oval. The dawn–dusk asymmetry is largest in the centre of the oval and decreases on both sides. It has been estimated (cf. Gustafsson, 1967) that the auroral orientation curves mentioned may be in error by a few degrees of latitude at the most, due to the integration errors, except at noon and midnight above a latitude of 78 degrees where too few data are available and the error may be greater. The change of the arcs' direction is large at about 78° of latitude. This introduces some uncertainty in this region, especially at night time.

The auroral orientation curves and the ovals of auroral occurrence

It was pointed out in the introduction that a close relation could be expected between the auroral oval and the auroral orientation curves. A comparison between the results published by Feldstein (1964*a*, *b*), Malville (1964), Lassen (1963), and Sandford (1964) shows (cf. Fig. 2) that the maximum of the auroral oval lies on the 67° curve of auroral orientation in the interval 14 to 00 hours corrected geomagnetic time, within the accuracy of measurements. The curve which crosses the midnight corrected geomagnetic meridian at 67° is called the 67° curve.

In the interval from 4 to 10 hours corrected geomagnetic time there is a large spread of the maximum of occurrence frequency. The data published by Sandford (1964) (relating to measurements originally made by Grodon) and Malville (1964) have been included in Fig. 2. It can be seen that the difference between the maxima is as large as 9 degrees of latitude for certain hours. If the location of the maximum is measured in the reference frame of the auroral orientation curves, the mean curve for Sandford's data is the 68.0° curve and for Malville's data the 65.8° curve in the 4 to 10 hour interval. However, it has not been possible to convert the data published by Sandford

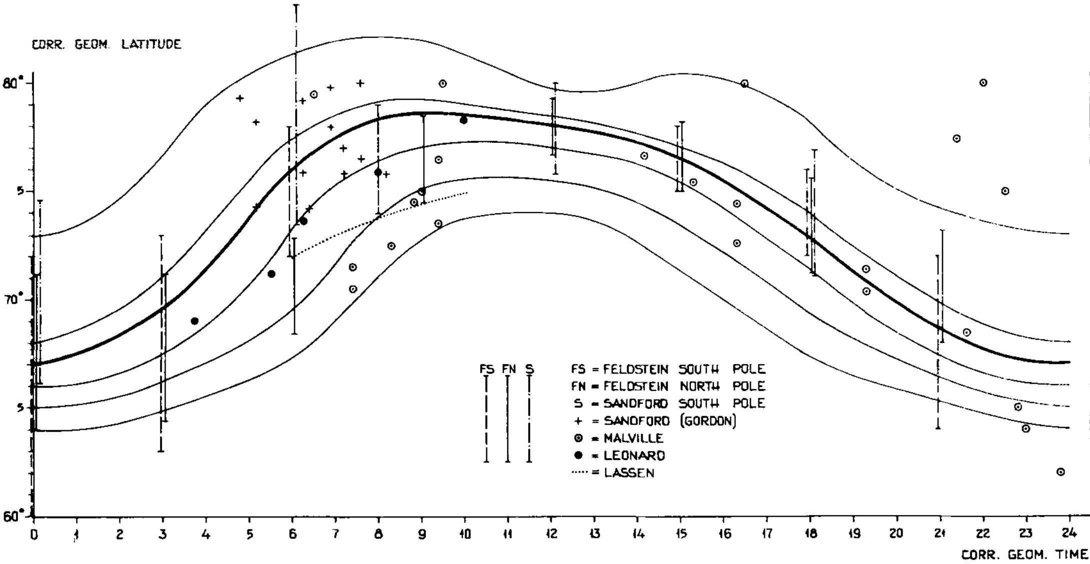

Fig. 2. The auroral orientation curves and auroral ovals from different sources. (The radar measurements by Leonard (1962) have also been included.)

which are given in auroral latitude into corrected geomagnetic latitude, but it has been pointed out by Sandford (1964) that the difference between the auroral latitude and the eccentric dipole latitude is small. The difference between the eccentric dipole latitude is less than 2.0 degrees for most of the auroral stations. Therefore it may be expected that the mean value for Sandford's data is the 68.0° ±0.5° curve the uncertainty arising from the coordinate system.

Lassen (1963) reported measurements for the northern hemisphere which closely agree with Malville's results. The centre of the auroral oval determined by Feldstein (1964) is between the 66° and 67° curve at all longitudes for both the northern and the southern hemisphere.

The reason for the spread of the maximum during daytime is probably that it is difficult to define the maxima of the curves of auroral occurrence as a function of time. They are rather flat from 06 to 18 hours, which is a natural consequence of the fact that stations located at a corrected geomagnetic latitude of 75° to 78° are within 2 latitude degrees from the center of the auroral oval during this period of time. The measuring technique also introduces some difficulties which will influence the results. The frequency ot occurrence is measured at a certain level of auroral intensity and this level may differ from station to station thus introducing an error when they are compared. This effect may be expected to be greatest in the morning because the aurora is usually weak, diffuse and widespread at that time.

The above difficulties do not affect the determination of the orientation of the auroral arcs. The auroral orientation curves may, therefore, be better defined than the auroral oval obtained from the frequency of occurrence of the aurora.

During the time interval 20 to 04 hours corrected geomagnetic time and for stations in the latitude region 67 to 73 degrees, a similar situation to that above occurs because the stations are close to the center of the auroral oval for several hours around midnight (cf. Malville, 1964). It is usually impossible to define a maximum of auroral occurrence after midnight in the presence of the large maximum before midnight.

The latitude region from 80° to 90° is a region where the orientation of the auroral arcs is different from that of the auroral oval region. However, it is interesting to note that in this region, the distance between the auroral curves and the auroral oval is shortest at the time when polar stations have maximum oc-

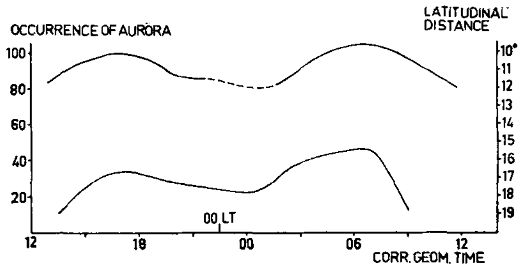

Fig. 3. Lower curve: Occurrence of the aurora at Resolute Bay. *Upper curve*: Distance between the orientation curve through Resolute Bay and the 67° curve.

currence of aurora. Fig. 3 shows the occurrence of the aurora at Resolute Bay (after Davis, 1962*a* and *b*) and the distance from the orientation curve through Resolute Bay and the 67° curve as a function of time. It can be seen from Fig. 3 that the correspondence between the maximum of auroral occurrence and the distance between the station and the auroral oval is good. The same relation also holds good for Alert and Thule. In Fig. 4 the 67° curve has been drawn and for the latitude range 80° to 90° the points which are closest to the 67° curve for each latitude circle have been plotted (corresponding to the minimum distances discussed in Fig. 3). It can be seen that in the morning places at about 80° of corrected geomagnetic latitude are closest at about 0830 hours and places closer to the pole at about 06 hours. In the afternoon locations at about 80° corrected geomagnetic latitude are closest at 1500 hours whereas regions nearer the pole are closest at 1800 hours. The measurements of the maxima of auroral occurrence which are also included in Fig. 4 show a similar pattern. The above relation, where stations close to the pole are nearest to the auroral oval at the time of maximum occurrence of aurora, indicates that at least a large part of the aurorae at these latitudes are closely related to the auroral activity in the auroral oval. This is somewhat surprising because it is well known that the aurorae above 80° of latitude are negatively correlated with the magnetic activity in the auroral oval. The occurrence of aurorae above 80° is small except during quiet magnetic conditions and the auroral oval has smaller dimensions than usual at this time but it may still have approximately the same shape, and the above relation may have some meaning in this case.

The mantel aurora (cf. Sandford, 1964) seems to have very little influence on the curves for the frequency of occurrence of the discrete aurora as measured by all sky cameras. Such a good correlation between the auroral oval and the orientation curves could otherwise not be expected.

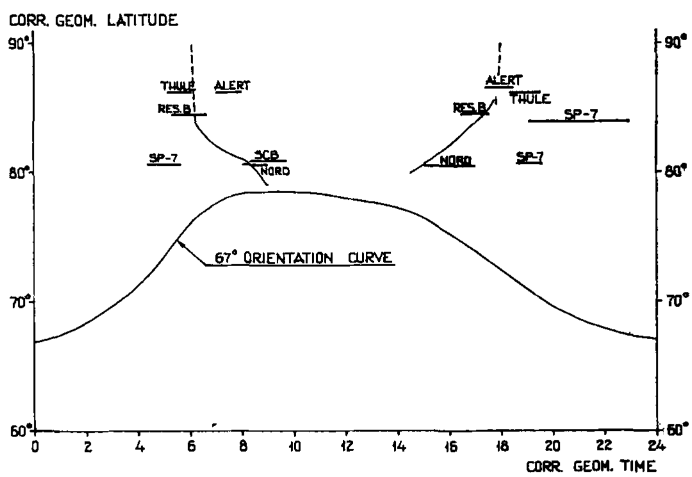

Fig. 4. The two diurnal maxima of auroral occurrence have been drawn for a number of stations above 80° corrected geomagnetic latitude. The full line means the two diurnal minima between a station at a latitude above 80° and the 67° curve.

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Table 1

	00^h	03^h	06^h	16^h	18^h	20^h
Eather & Sandford	—	67.2	68.0	66.0	67.5	66.8
Montalbetti & McEwen	65.0	66.3	65.6	65.5	66.0	65.5
Yevlashin	64.0	63.5	63.0	64.7	64.6	64.9

Auroral orientation curves and the occurrence of hydrogen emission and other upper atmospheric phenomena

A comparison between the hydrogen emission and the auroral orientation curves cannot be made in great detail because too little is known about the morphology of the hydrogen emission. Eather & Sandford (1966) made an investigation of the hydrogen emission at Mawson (eccentric dipole latitude $-71.0°$, corrected geomagnetic latitude $-70.6°$), Scott Base (ecc. lat. $-75.4°$, corr. lat. $-74.7°$) and Hallett (ecc. lat. $-76.0°$, corr. lat $-77.8°$). They also converted the results obtained by Montalbetti & McEwen (1962) and by Yevlashin (1963) into eccentric dipole coordinates. A summary of their results has been given in Table 1 where the centre of the published hydrogen ovals have been given in corresponding auroral orientation curves for different corrected geomagnetic times along the oval (e.g. 67.2 means the auroral orientation curve which is located at 67.2° of corrected geomagnetic latitude at midnight).

The table shows that the H-oval by Eather & Sandford is equatorward of the 68° curve (at all times when a comparison could be made) which was the auroral orientation curve giving the best fit to the auroral oval in the morning by Sandford (1964).

The two other ovals are always equatorward of the 66.3° curve. This can be compared with the auroral oval described by Feldstein (1964) which was centred around the 66.5° curve (see Section 3 of this report). From the above comparison it is found that the H-oval can be represented by an auroral orientation curve which is about one latitude degree to the equatorward side of the auroral oval at midnight, i.e. the 66° curve.

It is generally agreed that the H-oval is equatorward of the auroral oval before midnight but for the time interval after midnight some investigators have argued that the H-oval is on the poleward side of the auroral oval. It was mentioned in section 3 that this is a region where the uncertainty of the location of the auroral oval is large and Rees *et al.* (1961) found that it is difficult to trace the relation between the auroral oval and the proton emission during the morning hours.

An investigation has been carried out in order to study the relation between the southern border of the two emission lines $\lambda 4861$ Å and $\lambda 5577$ Å. Recordings made by photometers at Kiruna during a two-year period have been analysed. A total number of 40 clear nights with aurora have been studied individually. A typical case has been shown in Fig. 5. The location of the southern border (measured at an arbitrary intensity level) has been shown for the $\lambda 5577$ Å and the $\lambda 4861$ Å emission lines, for three consecutive nights, namely 20–23 January 1966. For comparison the 64° curve of auroral orientation has also been included. The figure illustrates the fact that the southern border of

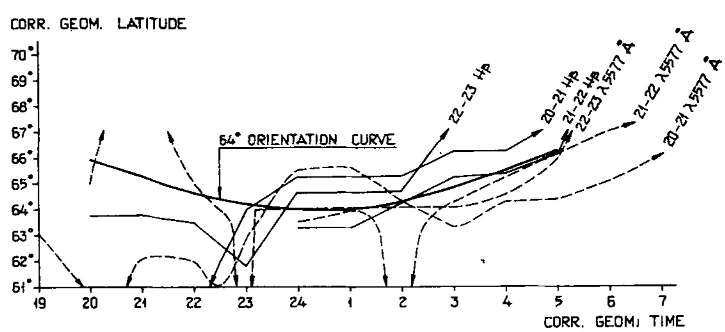

Fig. 5. Southern border of H_β and $\lambda 5577$ Å emission as a function of corrected geomagnetic time and latitude.

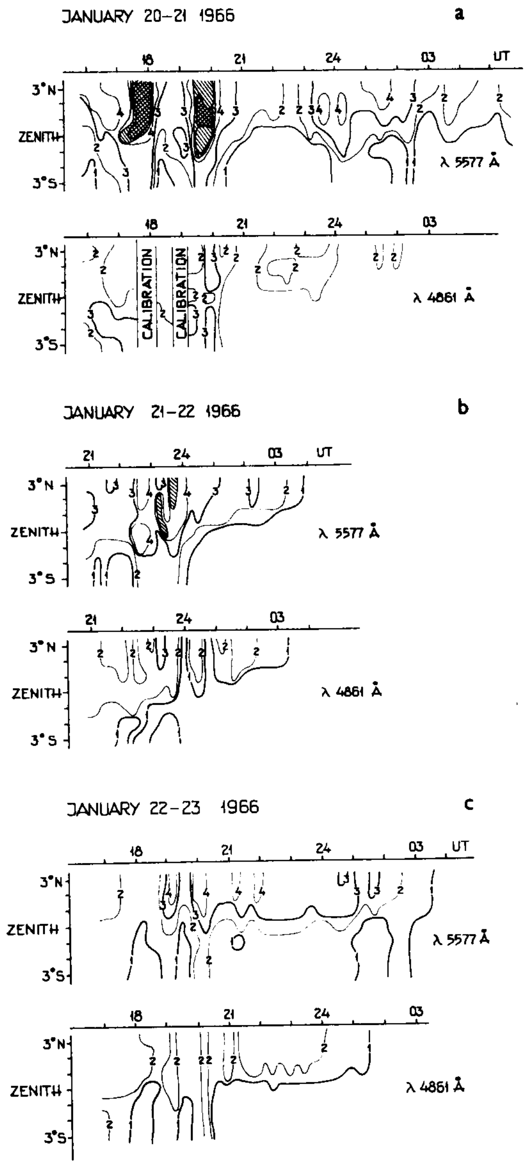

Fig. 6a–c. Intensity distribution of the $\lambda 5577$ Å and $\lambda 4861$ Å lines as a function of latitude and time. The intensity is plotted in a logarithmic scale. Intensity 2 means two times intensity 1.

the two phenomena varies sometimes independently. At 03 hours January 21 the $\lambda 5577$ Å border had moved 2 degrees southwards during the last two hours, while the $\lambda 4861$ Å border remained at the same latitude or moved northwards. The same effect occurred at 02 hours on January 22. The latitude distribution

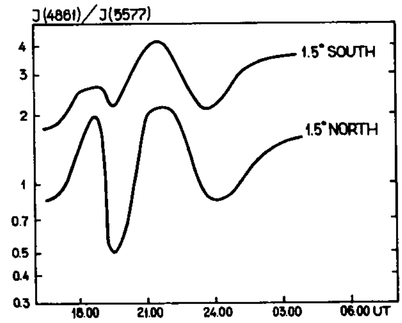

Fig. 7. The ratio between I(4861 Å) and I(5577 Å) as a function of time for 1.5° north and 1.5° south of Kiruna.

for corresponding time intervals of the $\lambda 5577$ Å and $\lambda 4861$ Å lines has been shown in Fig. 6*a–c*. The relative intensity has been given as a function of time along the geographic meridian through Kiruna from 3° of latitude north to 3° south. It can be seen that the maximum of the intensity of the green line is always to the north of Kiruna. The H_β-line has its maximum to the south of Kiruna between 16–18 hours *UT* and probably also between 04–05 hours, but during the time interval 20–02 hours the two intensity profiles are very similar in shape. It is interesting to compare the ratio $I(4861$ Å$)/I(5577$ Å$)$ for a 2 degree wide latitude interval centred 1.5° North of Kiruna and $I(4861$ Å$)/I(5577$ Å$)$ for an identical latitude band centered 1.5° South of Kiruna as a function of the time of day (cf. Fig. 7). The two ratios differ by a fairly constant value during the whole night and they do not indicate that the hydrogen emission changes its position relative to the $\lambda 5577$ Å emission in the morning hours. The ratio between the two curves of Fig. 7 is dependent both on the shape of the cross section of the two ovals and their location in latitude. The cross section of Fig. 7 is however, based on material which is too limited to make a conclusive quantitative calculation. The mean values were derived from 11 nights or more (up to 40). Another difficulty is that it is not known how much electron excited aurora contributes to the emission of H_β. The variation between the southern borders of the two phenomena is not necessarily related to the variation of the centres of intensity of the two ovals. They may expand in different ways. Montbriand & Vallance Jones (1962) reported that the hydrogen oval has its peak intensity along a wide arc near its equatorward border, while the auroral oval usually shows arc structure on the poleward side (cf. Davis & DeWitt, 1963). Therefore it is necessary to know the cross sections of the two phenomena as a function of latitude and time in order to determine the relative location of the two ovals. These cannot be obtained from a single station such as Kiruna (at 64° of corr. geom. latitude) because a latitude range of about 6° only can be covered.

The radio aurora and the visible aurora seem to be closely connected (cf. Leonard, 1962). Leonard used five auroral radars in Alaska and gave a diagram of the occurrence of radio aurora as a function of time and latitude. His data showed a large amount of scattering except in the time interval 03 to 10 hours (corrected geomagnetic time) where his data closely follow the 66° curve of auroral orientation (cf. Fig. 2).

It was mentioned in section 3 that the largest difference between the location of the auroral oval and the 67° orientation curve occurred in the time interval 04 to 10 hours corrected geomagnetic time. It has been found that the auroral orientation curves are closer to the pole in the morning than in the evening hours, but the auroral oval was asymmetric in the opposite direction. This may be compared with the location of the auroral electrojet as measured with the OGO-2 satellite by Langel & Cain (1967). They found that the position of the eastward electrojet at 1530 hours local time was more southerly than the westward electrojet at 0500 hours local time. Therefore, the electrojet seems to show the same asymmetry as the auroral orientation curves.

Satellite measurements of low energy protons and electrons have been made by e.g. Sharp *et al.* (1967). They measured the precipitation round midday and midnight. They found that the daytime precipitation was located in two distinct zones of invariant latitude, as compared with one well defined zone at night. As they measured only two cross sections of the auroral oval their data can be interpreted as two auroral ovals: one at about 70° of invariant latitude and one oval which is located at 70° at night and at 77° at noon or, alternatively, with an oval which has a spiral shape. The auroral orientation curves do not show any tendency towards a spiral structure and it is therefore difficult to believe that the auroral oval has a spiral shape. The oval of proton aurora may appear to have a spiral shape as a result of the morphology of the proton aurora not being too well known. Johnson (1966) reported from the same experiment that at 23 hours local time the precipitation of protons was always to the equatorward side of the precipitation region for the electrons.

Conclusions

A comparison has been made between the auroral orientation curves and the auroral oval determined from the occurrence of the aurora. It has been found that the 67° orientation curve (crossing the midnight meridian at 67° corrected geomagnetic latitude) is located within the auroral oval. However, the largest deviation occurs in the time interval 04 to 10 hours corrected geomagnetic time. The auroral orientation curves show an asymmetry in the dawn-dusk direction. They are about 4° closer to the pole at about 06 hours compared with 18 hours. The auroral oval has been located at different latitudes by different investigators in the time interval 04 to 10 hours corrected geomagnetic time. But the ovals which have been used for comparison here show no asymmetry or an asymmetry in the other direction. However it is difficult to estimate the auroral oval from the frequency of occurrence of the aurora in this time interval. Therefore, it is probable that the 67° orientation curve gives a better definition of the auroral oval in this time interval.

For a station in the latitude region 80° to 90° corrected geomagnetic latitude it has been found that the maximum of auroral occurrence occurs at the time of the day (very close to the pole this means at 06 and 18 hours) when the station is closest to the 67°-orientation curve. This indicates that the arcs in the polar region are of the same origin as the aurorae in the auroral oval.

The location of the auroral orientation curves in relation to the emission of hydrogen has been studied for a number of separate events and with statistical data. It has been found that the oval of hydrogen emission may be represented by the 66° orientation curve. However, the data are ambiguous in the morning hours. It is necessary to make photometer measurements of a cross section of the auroral oval over a long time interval in order to draw a firm conclusion.

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КРИВЫЕ ОРИЕНТАЦИИ ПОЛЯРНЫХ СИЯНИЙ И АВРОРАЛЬНЫЙ ОВАЛ

Произведено сравнение между кривыми ориентации полярных сияний и авроралным овалом, определенным по местам появления полярных сияний. Найдено, что кривая ориентации полярных сияний, пересекая полуночный меридиан при 67° подправленной геомагнитной широты, помещается внутри аврорального овала. Наибольшая разница в местоположениях овала и кривой ориентации при 67° наблюдается для утренних часов. Высказывается мнение, что кривые ориентации дают лучшее определение истинного овала полярных сияний в этот интервал времени. Кривые ориентации были соотнесены также с местами появления водородной эмиссии и было найдено, что кривая авроральной ориентации при 66° представляет овал для водородной эмиссии в часы, кроме утренних, когда данные противоречивы.