BRITISH (TERRA NOVA) ANTARCTIC EXPEDITION
1910--1913

OBSERVATIONS ON THE AURORA

BY

C. S. WRIGHT, O.B.E., M.C., B.A. (Research, Cantab.), M.A. (Toronto),
F.R.A.S., F.Inst.P.

LONDON:
PRINTED AND PUBLISHED BY
HARRISON AND SONS, LTD., 44-47, ST. MARTIN'S LANE, W.C. 2
FOR THE COMMITTEE OF THE CAPTAIN SCOTT ANTARCTIC FUND.

1921.

Price 7s. 6d. Net.

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The cost of the preparation and publication of this report has been defrayed from the Fund which was raised by public subscription in memory of Captain R. F. Scott and his companions.

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INTRODUCTION.

THE report which follows is based on data and sketches brought back on the termination of the Expedition, which remained in my charge and were not dealt with until the conclusion of the war.

In the normal course of events, they would have been sent to Dr. G. C. Simpson, F.R.S., for analysis, since the auroral observations were made under his direction. Only at the conclusion of the war were the data rediscovered, and they were then analysed by myself, owing to pressure on Dr. Simpson of work in connection with the meteorological report.

Though all members of the Expedition took their turn on the auroral watch, the credit for the observations lies chiefly with Dr. Simpson and with Major R. E. Priestley, who organised and directed the scientific work of the Northern party. The labours of the latter small party must indeed have been greatly increased by the burden of auroral observations taken every two hours during the winter, and very great credit is due to Priestley and to other members of this party for their zeal and energy.

One point which has not received attention in the report, but which cannot be allowed to escape notice, is that on our Expedition, as on others, reports were made that aurora had been seen at low altitudes and that a crackling noise accompanied the display.

The first instance was the report that aurora was visible between winter quarters at Cape Evans and Mt. Erebus. The whole scientific staff at once left the hut to investigate, but no such phenomenon was visible by that time. Major Priestley, however, informs me that a similar phenomenon was reported from Cape Royds during the Shackleton Expedition in 1908, this time by one of the scientific staff.*

A better authenticated case is reported by the Cape Adare observers, where on one occasion the aurora was reported *below* the stratus clouds (on April 30th, 1911).

On another occasion, it was reported by one of the seamen at Cape Adare that a rustling sound accompanied the auroral display (June 13th, 1911). This report was received with great scepticism, but Major Priestley informs me that, later, he himself heard the noise which he firmly believes was associated with the aurora (on July 23rd, 1911).

Though I have no personal knowledge of these two phenomena, it is clear that

* Dr. Simpson ('Nature,' Sept. 12th, 1918) has discussed all the reported cases, and has come to the conclusion, which is concurred in by the writer, that they were optical illusions.

the report should not neglect mention of them, and it is believed that other observers in the north have noted similar occurrences.

Dr. G. C. Simpson, F.R.S., and Dr. Charles Chree, F.R.S., have kindly criticised the greater portion of the report which follows, and my best thanks are especially due to the latter for his helpful interest in the work, and for supplying the whole of the tabulated magnetic character numbers.

C. S. W.

September 15th, 1921.

AURORAL OBSERVATIONS AT WINTER QUARTERS, CAPE EVANS, 1911.

1. Scope and Method of Observations.

The original plans for auroral observations in the Antarctic included provision for photographic determination of the height of the aurora after the method used by Professor Störmer in the Bossekop Expedition. For this purpose, portable telephones were kindly supplied by the National Telephone Company. Unfortunately, it was decided, after consultation with the photographer of the Expedition, that special lenses and photographic plates would not be necessary for this purpose. Repeated attempts, however, to photograph the aurora at Cape Evans, even with lengthy exposures, gave no results with the plates and cameras available, so this portion of the projected programme had to be abandoned.

For visual observations of the aurora, an "aurora watch" was established on the April 23rd, 1911, on the return of the various sledging parties. The duties of the watchmen of the night were to take meteorological observations at four-hourly intervals and to make hourly observations of the form, intensity, azimuth, and altitude of the aurora. Any very bright, or otherwise unusual auroral phenomena were to be reported to the meteorologist, and sketches were to be made of bright auroræ, or auroræ of unusual form. The whole of the "Afterguard" took turns in the aurora watch in 1911. Generally speaking, the watch was continuous only between 6 p.m. and 8 a.m., but commonly embraced the whole of the hours of darkness. Instructions were also given that any of the staff who were outside during the "daylight" hours should jot down in the aurora diary on their return any notes of auroræ they might have witnessed. It is possible, however, that this arrangement was not particularly satisfactory, judging by the very small number of observations recorded in "daylight" hours.

Though an attempt was made to record auroral observations at each exact hour during the darker portion of the day, observations at the exact hour were occasionally missed, but taken a few minutes before or later. For statistical purposes, such observations are treated as if they had been made at the exact hour, and it is unlikely that any appreciable error has been introduced thereby. On other occasions, pressure of more important work has precluded the taking of auroral observations for short periods, but these periods during 1911 were few and far between. On the other hand, a considerable number of additional observations, especially of auroræ of striking character, were recorded at times not falling on the exact hours. Except where specifically stated to be otherwise, such observations have been included in the formation of the Tables. It should be noted, however, that such observations were not recorded except in the case of a "positive" result, and the inclusion of these additional observations will, naturally, have most effect in increasing the number of auroræ of intensity greater than normal. It is, in fact, found that nearly all the intense auroræ are logged as occurring at times other than at an exact hour.

It is unfortunate that drawings were not made on each occasion the aurora was seen, the lack of diagrams greatly increasing the difficulty of working up the results.

In all that follows, unless it is specifically stated to be otherwise, the times are those of the 180th meridian and the directions are astronomical.

The position of Cape Evans Winter Quarters is Latitude 77° 38′ 24″ S., Longitude 166° 24′ 7″ E., so that time of the 180th meridian is approximately 54 minutes in advance of local time. Hours are numbered from 1 to 24, 1 hour being, therefore, approximately the time at which the sun was due south from the station. The magnetic declination at Cape Evans was about $154\frac{1}{2}$° East and the dip about 86° 26′.

A typical example of the changes in aurora seen at Cape Evans is furnished by the auroral observations of May 1st to May 3rd. The general course of the variations during that period was as follows :—

May 1st.

From 1 hour to 6 hours, no aurora was seen at the exact hours, though the sky was clear. A faint cloud-like patch was, however, seen between North and North 20° East at an altitude of 8°, at 4.10 a.m.

At 7 hours, faint streamers were observed between N.E. and S.E., rising to an altitude of 35°.

Observations were discontinued until 22 hours, when an incomplete arch, broken in the centre, was seen to extend from S.W. by S. to E.N.E. The arch was faint, the maximum altitude being about 50°.

At 23 hours, the aurora was still faint, in the form of a discontinuous arch of maximum altitude 20°, extending from E.N.E. to S.S.E.

At 23.55, the aurora was bright, in the form of three parallel arches extending from S.W. by S. to N.W. by N. almost across the zenith. These arches gradually coalesced and moved N.W. across the zenith, developing folds. The maximum brightness occurred just before crossing the zenith at 0.04 on May 2nd. There was little motion of detail and no colour could be seen. Unsuccessful attempts were made to take photographs at this time.

May 2nd.

The aurora was very faint at 0.18, the eastern limb at this time having moved round to north, the western limb remaining stationary. At the same time, a low faint arch of 10° altitude was seen between N.N.W and W.

The aurora at 1 hour was in the form of a single, broad, ill-defined arch extending across the zenith from North to S. by W.

At 1.30, three broad, parallel, hazy bands were seen in the western hemisphere, of which the uppermost extended from North to S.S.W. across the zenith, and the lowermost was at an altitude of 30° at its maximum.

At 2 hours, the only aurora visible was a very faint hazy patch of light in the S.S.W.

No aurora was seen at 3 hours and 4 hours, but at 4.07 a rather faint band (moderately bright in places), with little motion, was seen to extend from N.N.W. to S.E.

At 5 and 6 hours, no aurora was seen, but clouds were visible in the north. At 7 hours, faint patches of light were seen due East, at an altitude of 30°.

No observations were then recorded during the bright portion of the day, but, at 19 and 20 hours, the sky was clear, no aurora being visible.

At 21 hours, an arch was observed between N.E. and S.E. at an altitude of 25°, with streamers rising from the arch to an altitude of 40°.

The sky was clear and no aurora was visible at 22 hours, as also at 24 hours and at 1 hour on the 3rd May. At 23 hours, however, a very faint ill-defined patch of aurora was visible over the shoulder of Mt. Erebus (in the N.E.).

May 3rd.

A similar faint glow was seen in the same spot at 2 hours.

By 3 hours, the aurora had developed into a faint band stretching from N.E. to S.S.W. at a low altitude, with another band stretching from N.E. towards W.S.W. (altitude 60°), but fading away in the west. A faint glow was also seen slightly north of Mt. Erebus.

At 4 hours, the situation was little changed, except in respect of the second band, which had disappeared, its place being taken by an incomplete arch extending from N.N.E. to meet the first band about East of Cape Evans.

At 4.17, only a single band was to be seen stretching across the zenith from N.N.W. to South. A few isolated streamers were also visible between N.E. and South.

At 5 hours, a bright band was seen from N. by W. to N.E. at an altitude of about 20°, with a few isolated streamers above it and also in the East.

By 6.15, the auroral display had moderated to two low faint streamers South by East, the same condition also obtaining at 7 hours.

The above sequence of observations is typical (except as regards the trend of the arches) of many of the auroral displays, particularly in the tendency to the formation of arches and the sequence of aurora at successive hours, often broken by periods of "no aurora." It is worthy of note, also, that on all three days *special* mention is made of aurora between 4 hours and a few minutes past.

An auroral display was generally initiated by the appearance of streamers low down in the N.E. quadrant, in the late afternoon or evening. As the evening progressed these streamers increased in number and in altitude, at the same time appearing also in the adjacent quadrants. This tendency continued until about 4 a.m., when the aurora often passed overhead in the form of arches extending roughly from North to South. Later, the arches, moving at right angles to their trend, extended occasionally into the western quadrants.

For purposes of classification, auroræ were described under the following headings :—

(1) Glows, including cloud-like patches of indeterminate form. In the great majority of cases, glows were seen on, or very close to, the horizon.

(2) *Streamers.*—These appeared in the form of rays or cones, the apices being directed away from the horizon.

(3) *Arches or bands.*—This form of the aurora usually appeared straight when passing through the zenith and gently curved at other times, the curvature being always in the same sense. The aspect of these arches suggested that they were, in point of fact, straight bands in the upper atmosphere, the gently curved appearance being due to perspective.

(4) *Curtains.*—This designation was applied to auroræ, particularly when of curved shape, the radius of curvature varying both in sign and magnitude.

(5) *Corona.*—This term was applied to the aurora when in the form of discontinuous streamers at a high altitude, all streamers being directed towards a single point near the zenith. This form of aurora was only seen on two or three occasions at Cape Evans.

In a number of cases, streamers were associated both with arches at low altitudes, and with curtain forms. It seems probable, as Vegard suggests, that the streamer is the primitive form of auroral display, the aspect of other types being assumed according to the angle from which the streamers are viewed and the spacial distribution of the streamers.

2. Intensity of Aurora at Cape Evans.

Mention has already been made of the fact that aurora was rarely seen during the brighter portions of the day, even in the depth of winter. There can be no doubt, in fact, that the presence of very little twilight was sufficient to obscure all but the brightest auroræ seen at Cape Evans. The same holds true for auroral observations when the moon was above the horizon, and auroræ were very rarely seen close to a bright moon. This result is possibly due to the fact that the year was close to the sunspot minimum and unfavourable for auroral displays, but the result was felt to be disappointing in view of the restricted opportunities for observation. That the position of the station was not favourable for auroral observations appears to be substantiated by the fact that the colours (red or green) usually observed with bright auroræ were seldom seen, mention being made of colour on only 14 occasions during the year. On the occasions when it was estimated that aurora could have been readily seen, the phenomenon was actually recorded only about one hour in three ; on clear days during the dark hours, therefore, the observer was almost twice as likely to log " no aurora " as to record a positive result.

Apart from this restriction in the number of observations, due possibly to an unfavourable year and certainly to the unfavourable situation, the number of possible observations was even more seriously restricted by the unfavourable meteorological conditions. The sky remained overcast or a blizzard raged, often for days at a time, particularly during the winter of 1912.

This statement in regard to the low intensity of auroræ observed at Cape Evans appears to be borne out by the large proportion of "clear" hours on which no aurora could be seen, neglecting, that is to say, hours when meteorological or twilight conditions precluded the possibility of auroral observations.

Though auroral intensity was estimated in the majority of cases, it appears there was a tendency on the part of certain observers to avoid any mention of intensity in logging the other features. Neglecting such cases, there remain 463 observations between April 24th and September 30th, 1911, for which some indication is given in regard to auroral intensity. These 463 observations are divided up as follows :—

Very bright and bright	46	cases.
Moderate and fairly bright	169	,,
Faint	220	,,
Very faint	28	,,

The above groups of auroral intensity are, of course, relative, simply expressing the fact that, with reference to the mean brightness of all auroræ observed, this brightness was far exceeded in 46 cases, while the brightness was considered to be far less in 28 cases.

Corresponding to the same period (April 24th to September 30th, 1911), the number of observations of "Clear, no aurora" *at exact hours* was 605, on all occasions when twilight, moon and weather conditions did not preclude the possibility of recording a positive result. These two numbers, 605 and 463, are therefore not strictly comparable.*

Strictly comparable numbers are, however, available for the period May 13th to July 31st, inclusive, counting only observations at exact hours between 4 p.m. and 8 a.m. For this period, there were 656 occasions on which conditions for observation were favourable, while auroræ were recorded on only 236 occasions, or 36 per cent. of the whole.

The figures given above, showing the number of recorded observations of auroræ of various estimated brightnesses, are of more than passing interest, indicating as they do that the aurora at Cape Evans in 1911 tended to appear of definite brightness, the number of very faint and very bright auroræ being small in comparison with the number of auroræ of mean brightness. It would seem, therefore, that the frequent occurrence of "no aurora" is probably a real effect, corresponding to a total absence of aurora, rather than to occasions when the aurora was present, but of such low intensity as to be invisible to the eye. If this were not the case, one would, I think, expect to find a much higher proportion of auroræ in the "very faint" class.

* A record of "Clear, no aurora," was only logged at the exact hour, positive results being occasionally recorded also at other times.

One point worthy of notice in this connection is the comparatively frequent reference to arches in the sketches and log book. The same point is referred to by Mawson* in his discussion of the auroral observations at Shackleton's Winter Quarters in 1908. Our observations show that arches were observed at an altitude of 70°, or over, on 59 occasions in this period, while Mawson gives details of 118 occurrences at altitudes over 60° in the paper referred to.

Another point which appears to be of interest is the relative number of auroræ of all types which were observed at high altitudes, as it is not unreasonable to suppose, if we agree that auroral manifestations close to the zenith are, on the whole, closer to the observing station than those at low altitudes, that any physical factors closely connected with auroræ will be of enhanced importance at these times. During the whole of the period in question, auroræ were seen at altitudes of 70° and over on only 85 occasions.

It is equally interesting to note, from a perusal of the aurora log, the very small number of occasions when colour and movement (other than slow movement) is mentioned, a complete contrast in regard to "colour" being furnished by the Cape Adare observations. In all, at Cape Evans in 1911, colour (red and green) was recorded on only 14 occasions, and movement, other than slow movement, on only 24 occasions.

These figures are put on record, as it seems not improbable that they may assume importance in connection with any comparison of the relative suitability of stations for auroral observations.

3. Short Period Variations and Periodic Character of the Aurora.

Even a cursory study of the aurora log shows that the aurora undergoes considerable variations both in general form, in details of form and in intensity, during the course of a few minutes. The variations are, however, more pronounced in certain cases than in others. Thus, in the case of isolated streamers, short period variations are most pronounced, both as regards changes in position and in intensity, variations in form and position being more evident the higher the altitude of the aurora, and the variations in intensity being *apparently* greater, the greater the absolute brilliancy. The most stable forms of aurora are apparently the glows and arches so frequently observed, while the least stable in form are those of the curtain and streamer type. It is reasonable to assume that the variations of "glow" auroræ will generally not be very evident, on account of the low altitude and consequent great distance of these auroral forms from the observing station; while the constancy in form of the arches is explicable on the assumption that these are formed of connected rays or streamers viewed nearly end-on, the apices of the streamers being directed away from the observing station.

* "Auroral Observations at the Cape Royds Station," 'Trans. Roy. Soc. of South Australia,' Vol. XL., 1916.

Notwithstanding this variability in intensity and form from minute to minute, it is quite evident that the incidence of auroræ, both from hour to hour and from day to day, is governed by more or less definite laws. Thus, if the aurora is of unusual brightness during one hour of the day it is probable that the brightness will be above normal during the greater part of the same day. In other words, if a bright aurora is seen at one hour, the aurora will probably still be bright in succeeding hours of the same day.

Not only is this the case, but it may be taken as a general rule that a "disturbed" day will more likely be followed by another disturbed day than by a "quiet" day. This tendency for disturbed conditions to continue for more than one day may be readily seen from Table 1, which gives the days in 1911 which have been estimated as "disturbed," *i.e.* days of bright auroral display. From the Table, it will be seen that "runs" of several days are not uncommon, and there can be little doubt that these runs would have been even more pronounced if the meteorological conditions had been more favourable.

Table 1.—List of Disturbed Days, Cape Evans, 1911.

April 28.	July 1, 2, 3.
May 1, 2, 3.	July 19, 20, 21.
May 6, 7, 8, 9.	July 28, 29, 30, 31.
May 15, 16.	August 5.
May 19.	August 7.
May 21, 22.	August 26.
June 5, 6, 7, 8.	August 29.
June 22, 23, 24, 25.	September 3.
June 28, 29, 30 (mornings only).	September 7.
	September 13, 14.
	September 16, 17, 18, 19.
	September 22.

The converse of these cases appears to be equally true—that is, a quiet hour is likely to be followed by a quiet hour, and a quiet day by another quiet day.

Too much stress should, however, not be laid on the tendency indicated in Table 1 for the aurora to continue for several days at a time, as the days noted comprise a goodly proportion of all days when the moon was below the horizon.

By allotting to each day numbers from 0 to 4 according to the estimated auroral intensity shown on that day, extracting the days allotted numbers greater than 2, and comparing with the mean number for the preceding and following days, an estimate can be made of the tendency towards recurrence of strong auroræ on successive days.

The mean numbers for days $n-5$ to $n+5$, where n is the day showing intensity greater than 2, is given below and illustrated in fig. 1 :—

$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	$n+2$	$n+3$	$n+4$	$n+5$
1·47	1·47	2·12	2·14	2·62	3·27	2·35	2·00	1·98	1·34	1·62

There is, therefore, a real tendency for days of strong disturbance to be immediately preceded and followed by days of strong disturbance. This analysis is *not*, however, free from the disturbing influence of the moonlight in preventing auroræ from being visible.

Notwithstanding this tendency for disturbed auroral conditions to continue for a whole day and even for successive days, it is not at all infrequently found that, even on a fairly disturbed day, " no aurora " is logged at one or two of the hours of observation. This fact might, of course, be inferred from the preliminary statement in this section regarding short period variations in brightness; the remarkable fact being that the negative results recorded at these hours are very often duplicated at the same hours on the following day or even days.

An example of this tendency to the recurrence of " no aurora " at the same hour on successive days is given in Table 2.

TABLE 2.—Recurrence of Auroral Displays at the same hours on Successive Days, Cape Evans, 1911.

Time of Day.	June.				
	26th.	27th.	28th.	29th.	30th.
1 hour			×		
2 ,, ...		O		O	O
3 ,, ...		O			O
4 ,, ...		O		O	O
5 ,, ...			O	O	O
6 ,, ...	O	×	×	O	O
7 ,, ...		×	×	O	O
8 ,, ...	O	×	O	O	
9 ,, ...	O	×	O		O
10 ,, ...	O	×	O	O	
11 ,, ...	O	×	O	O	
12 ,, ...		×			
13 ,, ...		×			
14 ,, ...		×			
15 ,, ...					
16 ,, ...					
17 ,, ...					
18 ,, ...					
19 ,, ...					
20 ,, ...					
21 ,, ...					
22 ,, ...				×	
23 ,, ...				×	
24 ,, ...	O	O		×	

Hours on which aurora was observed are marked O.
Hours on which aurora could not be observed on account of weather conditions are marked ×.
Hours on which weather conditions were favourable but no aurora was observed are not marked.

Examples of the converse case are also common, an instance of the recurrence of special conditions at the same hour on succeeding days having already been given in Section 1. A better example is, however, furnished by the observations of May 16th to May 21st. Between these dates, May 17th and 18th were overcast, while no observations were made during the afternoon of the 20th.

On the 16th, a bright aurora was specially reported at 17.20, this time being between the regular hours (17 and 18) of observation. Aurora was again specially reported at 17.30 on the 19th and also at the same time on the 21st, no aurora being seen on this occasion at the adjacent regular hours of observation.

This tendency to recurrence at the same time on successive days is clearly an indication of a pronounced daily variation in the sequence of auroral conditions at Cape Evans, which is more clearly brought out in the following sections. That this tendency to recurrence of conditions extends also to the form assumed by the aurora, might be inferred from the remarks in Section 1 regarding the general course of the aurora during the day.

It would be of some importance to ascertain if auroræ show any tendency to recur after a period of about 27 days, corresponding to the period of rotation of the sun. For the purpose of this investigation, days have been divided into five classes—days on which auroral displays have been very brilliant, brilliant, fair, poor, or lacking in display entirely, these classes being given numbers 4, 3, 2, 1 and 0 respectively.

The results of the analysis must be considered inconclusive, possibly owing to the fewness of the observations. Taking all the days (n) allotted figures over 2, we obtained the following mean auroral character numbers on days between $(n+24)$ and $(n+32)$.

Mean auroral character for days $(n) = 3 \cdot 17$.

$(n+24)$	$(n+25)$	$(n+26)$	$\underline{(n+27)}$	$(n+28)$	$(n+29)$	$(n+30)$	$(n+31)$	$(n+32)$
1·79	1·62	2·16	2·41	2·38	2·15	1·55	1·47	1·30

From these numbers (shown also in fig. 2), it will be seen that there is almost as much evidence for a 28-day period as for a period of 27 days—a result which is by no means surprising when we consider the effect on auroral observations of the presence of moonlight. The result is, however, sufficiently definite to merit further investigation.

The rounded form of the curve is certainly to be expected if there is a direct connection between the recurrence of aurora and the recurrence of sunspots after one revolution of the sun, in view of the fact that the time of revolution in the sun varies with latitude. In addition, the rounded form must owe its shape in some degree to the fact that disturbed auroral conditions show a tendency to continue sometimes for several days at a time. How far this may be due to sunspot conditions cannot be estimated.

No attempt was made to obtain evidence of an annual variation in the number of auroræ seen, in view of the impossibility of estimating the effect of the twilight arch (in rendering the aurora invisible) and the difficulty of making a correct allowance for the variations in weather conditions during the winter months.

4. Trend and Rotation of Arches.

Mawson,* in his treatment of the auroral observations of Shackleton's Expedition in 1908, gives a full discussion of the occurrence of arches at that station, and records a definite and close correspondence between the trend of the arch and the sun's azimuth, *i.e.* a dependence of trend upon local time.

An analysis of the 59 observations of arches of 70° altitude and over at Cape Evans during the dark period in 1911 does not completely confirm Mawson's results, as may be seen from Table 3.

Table 3.—Trend of Arches, Cape Evans, 1911.

Trend.	Number of Observations.	Cape Evans Times of Observation.†
N. to S.	12	23.35, 1, 2, 2, 3, 3, 3, 4, 4, 5, 8, 9 hours.
N.N.W. to S.S.E. ...	5	4.17, 4.30, 5.15, 5.30, 5.
N.W. to S.E.... ...	13	0.30, 2, 3, 4, 4.07, 5, 5, 5, 5.04, 6, 8.03, 9.30, 10.
W.N.W. to E.S.E. ...	1	5.45.
W. to E.	4	15.15, 23.35, 1, 5.50.
W.S.W. to E.N.E. ...	0	
S.W. to N.E.... ...	15	22, 23.55, 0.12, 22.30, 23, 1, 1.30, 2, 2, 3, 3, 4, 2, 3, 4.
S.S.W. to N.N.E. ...	9	23, 24, 24, 0.18, 1, 1, 1.30, 4, 4.11.

As, in this Table, prominence has obviously been given to the eight chief points of the compass at the expense of such directions as N.N.W., W.N.W., etc., the Table has been re-tabulated below, one-half of the number of observations in the subsidiary directions being added to each of the adjacent chief points of the compass:—

Trend.	No. of Observations.
N. to S.	19
N.W. to S.E.	16
W. to E.	$4\frac{1}{2}$
S.W. to N.E.	$19\frac{1}{2}$

The remarkable point disclosed by these figures is the tendency of such arches to avoid the East-West direction.

The point to which attention has been drawn by Mawson (*loc. cit.*) is the general rotation exhibited by the arches observed by him, this rotation being sometimes quick and sometimes slow. (The rotation of the arch is a necessity if his statement in regard to the relation between local time and trend of arch is correct.)

* *Loc. cit.*

† Time of 180th meridian, which is about 54 minutes in advance of local time.

No corroboratory evidence can be offered on this point as a result of the present observations. Though in about half the number of cases there was a more or less regular rotation (with the sun) of the arches, the trend of the arches remained fixed in many other cases. Only two observations were, however, recorded in which there was slight rotation in the reverse direction, both these cases having been immediately preceded by a slight rotation in the usual direction. Some evidence on this point can be drawn, however, from Table 3. From this Table, it will be seen that there is a tendency for arches with any given trend to be grouped about a more or less definite time, though variations from this mean time up to 6 hours are not unknown. The *average* time corresponding to various trends of arches are given below :—

S.W.–N.E.	1 hr. 20.
S.S.W.–N.N.E.	1 hr. 20.
S.–N.	3 hr. 30.
S.S.E.–N.N.W.	5 hr. 00.
S.E.–N.W.	5 hr. 00.

There is, therefore, some evidence for a rotation of the arch in the sense of the apparent movement of the sun, but, on the other hand, there seems to be no indication whatever of a tendency for a given trend to recur twice a day, at intervals of 12 hours. (Owing to the twilight arch, it is hardly to be expected that a double periodicity would be indicated, except in the case of arches running from N.W. to S.E. at 5 hours, at which time observations are possible at the same hour in the morning and the afternoon.)

5. Distribution of Aurora in Azimuth.

As indicated in Table 4, auroræ show a strong preference for certain sectors and aversion for others. In this Table, column 2 gives the number of occasions on which auroræ were recorded in the sector North to North-East, column 3 the number of occasions recorded in the sector North-East to East, and so on. The period referred to is from April 24th to September 30th, 1911, inclusive, observations at exact hours alone being counted.

Table 4.—Distribution of Aurora in Azimuth, Cape Evans, 1911.

Period.	N. to N.E.	N.E. to E.	E. to S.E.	S.E. to S.	S. to S.W.	S.W. to W.	W. to N.W.	N.W. to N.
(1) April 24th–Sept. 30th...	227	278	221	164	91	46	50	105
(2) May 13th–July 31st (only).	137	167	137	103	50	27	33	67
	28	35	28	20	11	6	6	13
	27	33	27	21	10	5	7	13

From the Table, it is seen that auroræ are most likely to be seen in the sector N.E. to E., and least likely to be seen in the sectors S.W. to W. and W. to N.W. The Table also gives the corresponding figures for the period May 13th to July 31st, comprising 78 days in the darkest portion of the year. Not only are the figures for this period in qualitative agreement with those for the whole period, but they are also very closely in quantitative agreement. Division by eight of the figures for the whole period, and by five of the figures for the dark period, gives the numbers shown in the last two lines, which are seen to be in very close accordance. Fig. 3 gives a graphical representation of the variation in azimuth for the longer period.

Not only are the figures accordant for the two periods shown in Table 4, but even for very short periods of one or two weeks the same general tendency is shown. Numbers similar to those in Table 4 have, in fact, been compiled for the first and last halves of each month, and the azimuth of maximum frequency of aurora is, in each period, found to lie either in the sector N.E. to East, or in one of the two adjacent sectors. The minimum is even more definitely defined, generally in the sector S.W. to W., but sometimes in the sector N.W. to W.

Though the method of observation at Cape Evans differed from that employed on the previous Shackleton Expedition, the figures in Table 4 are in very close agreement with those of Mawson (1908), indicating that the relation shown in fig. 1 is characteristic of the situation of Winter Quarters. (Only a few miles separated the two Headquarters in question.)

It is possibly worth noting that the azimuths for maximum and minimum frequency are almost, but not quite, separated by 180°.

It is also important to note that the distribution in azimuth is apparently unaffected by the presence of the daylight arch in the spring and autumn, which suggests that the characteristic distribution in azimuth is about the same during daylight hours as during the darker hours of the day.

Mention has already been made of the fact that auroral displays appeared commonly to originate in the N.E. or E., sometimes moving to a point directly overhead, or passing overhead, during the maximum display. This tendency is expressed in the statement that auroræ were only seen in the "rare sectors" (N.W. to W. and W. to S.W.) at times of maximum display, but were seen in the "common sectors" even at times of minimum display. As will be seen later, this tendency is of a most persistent character.

6. Distribution of Aurora with respect to Time.

An analysis of all observations between May 13th and July 31st, with respect to both azimuth and time, is given in Table 5, which shows the number of occasions during this period on which aurora was seen in each sector at each hour of the day. Results are almost entirely lacking for the twilight hours, as, even during the darkest portion of the year, there was sufficient light at noon to obscure any but the brightest auroræ seen at Cape Evans.

TABLE 5.—Distribution of Aurora at different times of day, Cape Evans, 1911.

Hour (Time of 180°).	N. to N.E.	N.E. to E.	E. to S.E.	S.E. to S.	S. to S.W.	S.W. to W.	W. to N.W.	N.W. to N.	Number of Occurrences in all Sectors.	Number of Observations.*
1	3	5	4	7	6	1	1	1	28	10
2	7	10	9	9	5	2	2	3	47	16
3	14	13	7	7	5	4	3	5	58	18
4	21	17	11	9	6	5	6	15	90	27
5	14	16	10	7	4	4	4	9	68	23
6	12	11	12	13	2	2	6	10	68	22
7	11	11	9	6	2	1	2	5	47	22
8	15	21	16	7	2	2	3	3	69	25
9	6	10	8	4	0	0	0	1	29	12
10	5	6	4	2	1	0	1	2	21	10
11	1	4	3	2	0	0	0	0	10	5
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	1	1	0	0	0	0	0	2	1
15	0	2	2	1	1	0	0	0	6	3
16	3	4	2	2	1	0	0	1	13	6
17	1	4	4	3	1	0	0	0	13	7
18	1	2	2	1	1	1	1	1	10	4
19	0	1	3	2	0	0	0	0	6	4
20	2	2	2	1	0	1	2	2	12	5
21	4	8	9	4	0	0	0	0	25	10
22	7	7	3	2	2	0	1	2	24	11
23	4	5	6	8	8	3	0	3	37	13
24	6	7	10	6	3	1	1	4	38	13
	137	167	137	103	50	27	33	67		

The Table shows, in the first place, that at almost every hour of the day, aurora is most likely to occur in the North-East or East, or in one of the adjoining sectors. The "rare sectors" are equally clearly shown for all hours of the day. In the second place, there is a fairly definite tendency towards a maximum of frequency, in almost all sectors, between 4 and 8 hours (time of 180th meridian). An exception is, however, afforded for the quadrant S. to S.W., the maximum appearing at 23 hours in this case.

In the Table, the sum of all the numbers for each sector is formed in the penultimate column headed "Number of occurrences in all sectors," while the last column shows the "Number of observations" of aurora at each hour. The figures in the penultimate column are, therefore, those in the last column weighted by a number more or less proportional to the extent of the aurora. Little qualitative difference shows itself between the two columns, however, the ratio of the numbers in the two columns

* In some measure, the small number of observations between 9 hours and 19 hours is due to the fact that observations were not always made in this period.

varying from 2/1 to 3/1, the former ratio being characteristic of the hours of less frequent occurrence, and the latter ratio characteristic of the hours of more frequent occurrence of aurora. This difference simply expresses, therefore, the fact that aurora is not only most likely to be seen at certain hours, but is also of greater extent at the same hours. This agrees with what has been stated before, viz., that the manifestations of aurora appear to originate in a definite quarter, being seen low down on the horizon at hours of minimum frequency and minimum display, approaching the station (increasing in altitude) as the hour of maximum display and maximum frequency approaches.

In addition to the principal maximum at 4 hours, indications appear of a secondary maximum at 16 or 17 hours, followed by a minimum at 19 hours. The minimum at 12–13 hours is, of course, due to twilight, local noon being at about 13 hours. That the minimum in the late afternoon is a real one can hardly be doubted, when one considers that, at the equally dark hour in the morning corresponding to (say) 18 hours, auroræ are about six times as likely to be seen as at the latter hour.*

Though the number of observations is small at any particular hour, it is to be remarked that the observations of Shackleton's Expedition are in fairly close agreement with ours. Thus Mawson records a principal maximum at 3 hours, a minimum at 17–20 hours, and a secondary maximum at 16–17 hours. Mawson's observations differ from those of the present Expedition, however, in that auroræ were less frequently seen in the late morning than in the corresponding early afternoon hours (*i.e.* hours equally distant from local noon). However, the observations of the two expeditions are not strictly comparable, as apart from the different methods of observation, Mawson's results refer only to the months of June, July and August.

In addition, the local surroundings (hills and mountains) of any observing station must affect the distribution to some extent, and at neither station was a clear view afforded to the horizon.

The observations by Bernacchi on the previous Scott Expedition, whose winter quarters were also not far removed from the present Expedition, indicated in 1903 a maximum at 2 hours (local time) with a subsidiary maximum at 16 hours and a succeeding minimum at 18 hours. In view of the restricted field of view from that station the agreement is very good. It is of great interest, however, to note that in 1902 no trace was observable of the secondary maximum in the afternoon.

7. Diurnal Frequency of Different Types of Aurora.

Aurora of 70° altitude or over.

Analysis of the whole of the observations in 1911 (85 cases) when aurora was seen from Cape Evans at an altitude of 70° or over, shows a well-marked diurnal frequency

* *See* footnote to preceding page. If the organized watch had included observations at 18 hours, this disproportionality would have been reduced to some extent. In support of the reality of the secondary maximum, it can be stated that the maximum is not the result of more frequent observation of the sky during this period.

similar to that shown in Table 5 for the observations in the darkest portion of the year. The figures expressing this frequency are given in Table 6.

TABLE 6.—Diurnal Frequency of Aurora (70° altitude and over), Cape Evans, 1911.

Hour ending ...	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Number of occasions	10	12	9	10	18	7	0	2	2	0	0	0	1	0	0	1	1	1	0	0	0	0	4	7

The maximum between the hours of 4 and 5 is even more clearly marked than in Table 5, while the complete absence of aurora at this altitude between 19 and 22 hours is clear indication of a minimum about this time. This confirms our previous statement that the tendency of the aurora is to spread to the Cape Evans neighbourhood only at hours of maximum frequency, *i.e.* in the early morning.

Aurora in N.W. to W. and W. to S.W. Sectors.

The same statement is true for auroræ seen between N.W. and S.W., these sectors being those in which aurora is most seldom observed. On the view that the aurora spreads from the E.N.E. and only passes over the station at Cape Evans into the above two sectors at times of maximum frequency, it is to be expected that the diurnal frequency for auroræ in these sectors would be very similar to that for auroræ seen close to the zenith. Table 7, giving an analysis of the 85 occasions observed in 1911,

TABLE 7.—Diurnal Frequency of Aurora seen between N.W. and S.W., Cape Evans, 1911.

Hour ending ...	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Number of occasions	6	10	9	8	13	14	2	3	2	0	1	0	0	0	0	1	0	2	1	2	0	1	5	5

shows that the two cases are closely parallel, the maximum, however, occurring earlier in the morning for auroræ near the zenith.

Aurora showing Colour and Movement.

An attempt was also made to analyse the frequency of those cases of aurora in which special mention was made of colour or movement. The number of such cases was very small, but the result which disclosed itself was, that for 17 observations in the forenoon there were 19 observations in the afternoon, a result in direct opposition to the figures given in the preceding Tables. Though the number of cases was few, there seems little doubt that the figures disclose a real tendency, the maxima being roughly at 18 and 23 hours, with a minimum at 21 hours, which is much less definitely indicated.

For reasons which seemed adequate at the time, the opinion was formed while in the Antarctic that auroræ showing colour and movement were the most intense, and this is substantiated by the results of the analysis of these classes in respect of the corresponding " magnetic " character numbers.

Diurnal Frequency and Brightness of Aurora.

For this analysis, the auroræ have been divided into two classes only (where no mention of brightness of aurora was made in the log, the observations have been neglected)—one class comprising bright, moderately bright and fairly bright auroræ, the other class faint and very faint auroræ, all the observations of 1911 being included. A third class is also formed of all observations at certain even hours where the aurora log records " Clear, no aurora." The figures which are given in Table 8 are of considerable interest.

TABLE 8.—Diurnal Frequency and Brightness of Aurora, Cape Evans, 1911.

Hour of Day.	Bright and Moderately Bright Aurora. A	Faint and Very Faint Aurora. B	" Clear, no Aurora." C	$\frac{C}{A+B}$.
1 hour	12	13	47	1·9
2 ,, ...	14	25	36	0·9
3 ,, ...	9	23	39	1·2
4 ,, ...	16	26	33	0·8
5 ,, ...	14	22	33	0·9
6 ,, ...	11	22	34	1·0
7 ,, ...	5	21	19	0·7
8 ,, ...	12	13		
9 ,, ...	12	15		
10 ,, ...	5	3		
11 ,, ...	2	4		
12 ,, ...	1	0		
13 ,, ...	4	0		
14 ,, ...	0	1		
15 ,, ...	2	2		
16 ,, ...	6	3		
17 ,, ...	7	4		
18 ,, ...	10	2		
19 ,, ...	8	2	34	3·4
20 ,, ...	4	6	46	4·6
21 ,, ...	6	7	47	3·6
22 ,, ...	15	14	52	1·8
23 ,, ...	18	11	48	1·7
24 ,, ...	16	11	48	1·8

In the first instance, the Table shows that the diurnal variation of frequency for faint auroræ is of the normal type, with a principal maximum at 4 hours. The numbers of auroræ of average brightness and over are, on the contrary, much more evenly distributed throughout the day, and it will be observed that there is a strong family resemblance to auroræ showing colour and movement, particularly as regards the afternoon maxima and minimum.

(It will be noted that the combined figures for faint and bright auroræ give a diurnal frequency with maxima at 4 hours and 18 hours, and a minimum at 19 or 20 hours; these times being little different from those derived from figures relating only to the darkest days of the year.)

As is to be expected, the value of the ratio—number of observations of no aurora (when conditions were favourable for observations) to the number of occasions when aurora was observed—varies during the course of the day, the smallest value of this ratio being in the morning (1·0) and the largest value in the evening (2·3).

It is unfortunate that the number of observations is so small, but at least it is clear that the number of bright auroræ exceeds the number of faint auroræ in the afternoon, while the reverse is true in the forenoon.

The figures for the few auroræ classed as "very bright" and "bright" give an even more definite result, the number of such auroræ seen in the afternoon being actually greater than the number in the forenoon, while for the "very faint" class the morning observations of auroræ are three times as numerous as the afternoon observations.

The hours when auroræ are most likely to be brilliant are, therefore, the hours when auroræ are least likely to be seen at high altitudes from Cape Evans—that is, close to the station. Faint auroræ, on the other hand, are most likely to occur at times when auroræ are most likely to be seen close overhead.

Diurnal Frequency of "No Aurora."

In Table 8 is also shown the number of occasions at exact hours when the weather was clear and suitable for observation of auroræ, though none was seen. The period in question was the whole period from April 24th to September 30th, 1911.

As might no doubt be expected the minimum occurs at 4 or 5 hours, but the maximum occurs at 22 hours, two or three hours later than the general aurora minimum. Neither maximum nor minimum is, however, sharply defined, and this is possibly to be expected when it is considered that the number of negative greatly exceeds the number of positive observations.

AURORAL OBSERVATIONS AT WINTER QUARTERS, CAPE EVANS, 1912.

Originally it was not intended to discuss the observations of 1912 in view of the restricted opportunities for observation during that winter, caused by the extraordinarily unfavourable weather. As Bernacchi, however, had found that the daily variation of the aurora in 1902 differed from that in 1903 by the suppression of the secondary auroral maximum in the afternoon, it seemed desirable to ascertain if there was any such difference between the years 1911 and 1912.

The data have, however, been found to be much too scanty for any definite decision to be given on this point. Even in 1911, the number of afternoon observations at any hour was small, and in 1912 the number was even smaller.

The figures available are given in the Table below for each hour of the day in the period May 13th–July 31st, 1912. The numbers are comparable with those in the last column of Table 5.

Hour of day ...	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
No. of observations	7	4	8	10	11	11	10	7	7	2	2	3	0	1	1	2	1	0	2	1	5	1	6	6

The total number of occasions on which auroræ were observed during this period in 1912 was 108, corresponding to 267 in the same period of 1911.

In view of the fact that 1911 was magnetically more disturbed than 1912, there is the possibility that the poverty of aurora in the second year owed something to this fact. It is to be noted, however, that the ratio of the number of occasions on which aurora was not observed, though conditions were favourable, to the number of occasions on which aurora was observed at exact hours during the period is almost the same in the two years, suggesting that the poverty of auroral observations in the second year was primarily due to the unfavourable weather conditions.

AURORAL OBSERVATIONS AT WINTER QUARTERS, CAPE ADARE, 1911.

1. Scope and Method of Observation.

The auroral observations at Cape Adare, the Winter Quarters of the Northern Party during the winter months of 1911, were in charge of Major R. E. Priestley, M.C., R.E. As the whole party comprised only six persons, it was not expected that a complete programme of auroral observations would be carried out during the whole of the winter months. Notwithstanding the small number of persons available for observations, these are in some measure more complete than those of the Main Party, and bear eloquent testimony to the zeal with which the whole party, including the seamen, applied themselves to the scientific work, as the duty of keeping a continuous watch for auroræ during the night was no light task for so small a party.

The scheme of the observations contemplated regular two-hourly records of the aurora during the dark hours, and this programme was carried out for the period May 26th to July 31st, after which date sledging commenced. Observations were, however, made both before and after these dates, when practicable. In addition to the observations at the even hours, numerous observations (with sketches) were made between these hours, particularly when the aurora was of a striking nature; the records also include periods of an hour or more, when observations were taken and sketches made every few minutes. As in the case of the Cape Evans observations, a note was made of the intensity and colour of the aurora; the observations are more complete, however, in that a sketch has been made to illustrate each note. As in the case of the Main Party, regular observations between 10 and 16 hours are rare. The regular observations were almost always made at the exact even hours.

Except where specifically stated to be otherwise, all Tables refer to the period above mentioned (*i.e.* May 26th to July 31st, when the observations were taken regularly every two hours), all observations during this period being included.

In all that follows, unless specifically stated to be otherwise, the times are local mean time, and the directions are astronomical.

The position of the Cape Adare station is Latitude 71° 18′ S., Longitude 170° 9′ E., local noon occurring therefore about 40 minutes after noon time of the 180th meridian. Hours are numbered from 1 to 24.

As a sample description of a typical aurora at Cape Adare, of *inferior* brilliancy, the following observations of the 14th July are given:—

> At 20 hours, a long glow in the form of a vivid green arch, was seen from N.W. to N. 30° E., where it dipped behind Cape Adare, but a series of curtains doubled back towards the North from behind clouds to the E.N.E. At the

lower end of the curtains, there was a distinct tinge of orange-yellow or violet. The light was moving backwards and forwards.

This aurora almost immediately disappeared, and did not return until 20.40 when it showed as a single glow in arch form low down on the horizon in the N.W., disappearing behind Cape Adare in N. 20° E.

The next phase consisted in the appearance of a second glow at an altitude of about 15°, from North to N. 20° E., where it went behind Cape Adare. This upper glow increased in intensity, broadened at the end resting on Cape Adare and spread towards the N.W. Its northern end gradually doubled and one portion rose to an altitude of 20°, while two long streamers were given off towards the zenith at North and N. 20° W. The lower glow now disappeared. The aurora then became very faint, the glow broke up, and the light seemed to concentrate into definite streamers, arranged in the form of a curved arch from North to N.W. and back to N. 20° W., but soon the glow reasserted itself without any change in the shape of the arch.

At 21 hours, the aurora again assumed the form of a simple arch from N.W. to North, vivid green with a tinge of yellow, and with streamers shooting towards the zenith to an altitude of 5°–12°. The arch afterwards broke up into streamers and faded away.

A vivid glow next formed from North to N. 10° W., and from it streamers shot towards the zenith. It afterwards spread in arch form towards the west, and another bright spot appeared above Cape Adare in N. 30° E.

Finally, an uninterrupted glow in the form of an arch appeared from the N.W. to Cape Adare in N. 30° E. (at 21·13 hours). This remained for a few minutes, now continuous and now breaking into streamers. For 10 minutes, the aurora then concentrated into a vivid glow from North to N. 20° E.; from the glow, streamers shot towards the zenith, reaching an altitude between 30° and 40°. This was the highest altitude reached during the display, which faded away between 21·30 and 21·45.

2. Intensity of Aurora at Cape Adare.

There can be no doubt that the intrinsic brightness of the aurora was far greater at Cape Adare than at Cape Evans. The example cited at the conclusion of the last section as descriptive of an aurora of *inferior* brilliance would have been an aurora of remarkable brilliance at Cape Evans. Further evidence on this point is abundant. The appearance of colour (chiefly green) was the rule at Cape Adare, not the exception; mention is made on one occasion of the light of the aurora being seen reflected from an iceberg; a note appears to the effect that the light of the full moon "is not sufficient to hide a brilliant aurora," a result totally at variance with the observations at Cape Evans.

In addition, Major Priestley, who was also a member of the Shackleton Expedition in 1908, whose winter quarters were located only a few miles from the main quarters of the present Expedition at Cape Evans, states most definitely that the auroræ observed at Cape Adare in 1911 were very much brighter than those seen on the previous Expedition in 1908.

Not only was the brightness of the Cape Adare aurora greater than that observed at Cape Evans, but also the number of occasions on which aurora was observed, taking due account of the fact that observations were only made every second hour at Cape Adare. It is, in fact, estimated that auroræ were seen on 64 per cent. of the possible occasions, *i.e.* on about two in three observations when the meteorological conditions were favourable, corresponding with one in three (about) in the case of the Cape Evans observations.

Apart from this, Cape Adare did not suffer very seriously in 1911 from bad weather. The Cape Adare observations are, therefore, a most valuable check on those taken at Cape Evans, besides providing a great deal of independent data.

Of the 398 occasions during the whole period of observation, where a note is made of the brightness of the aurora—

69	are logged	as	"bright."
93	,,	,,	"average brightness or above."
170	,,	,,	"average brightness or below."
66	,,	,,	"faint."

During the period May 26th to July 31st, auroræ were observed at the even hours on 232 occasions. As was the case at Cape Evans, a large number of arches was observed at an altitude of 70° or over—in all, on 69 occasions.

During the same period (taking all observations), auroræ were seen at altitudes of 70° or over on 148 occasions, glows being recorded on 122 occasions and colour mentioned on 153 occasions.

The frequent occurrence of auroræ at high altitudes and the large number of occasions on which definite mention is made of coloured auroræ form a complete antithesis to the Cape Evans observations.

3. Short Period Variations and Period Character of the Aurora.

There is no evidence to show that auroræ as viewed from Cape Adare were more variable in character, or in intensity, than the auroræ seen at Cape Evans, the same tendency to variation being equally strong at both stations, so far as can be judged.

There was a tendency also at Cape Adare for auroral displays to continue for hours at a time, and sometimes even for days, though this tendency did not appear to be so marked at Cape Adare as at Cape Evans. It may, however, be that the difference between the two stations in this regard is due largely to the fact that the presence of moonlight did not affect the aurora observations at Cape Adare to the same extent as at Cape Evans.

Some evidence can, however, be offered on the subject of the tendency to repetition of conditions at the same hour on successive days, this result being largely possible on account of the relatively favourable weather conditions at this station. As an example, we may take the observations at 2 hours between the 26th May and the 31st July, at which hour conditions were favourable for observation on 45 occasions. Thirty-two times out of this possible 45 aurora was seen, a "nil" result being recorded on the remaining 13 occasions. During this period of 67 days, the following sequences of aurora on successive days were observed :—

On 1 occasion, 6 days in succession.
,, 1 ,, 5 ,, ,,
,, 3 ,, 4 ,, ,,
,, 2 ,, 2 ,, ,,

A "nil" result was recorded during one period of four days, and on two occasions for two successive days.

If the occurrence of an aurora was subject only to the laws of probability, we would estimate that the chance of the occurrence of an aurora on any one day was 32/45, and the chance of the occurrence of an aurora on six successive days was $(32/45)^6$, while the chance of the occurrence of four successive "nils" would be $(13/45)^4$. Considering further that, during the period of 67 days, a sequence of six was only possible on four occasions owing to unfavourable weather conditions, it seems very clear that there must be a strong tendency for the same conditions to recur at the same time on successive days.

Not only is this the case, but a scrutiny of the Cape Adare log shows most definitely that there is a marked tendency for the aurora to recur *in similar form* at the same time on successive days. So pronounced is this tendency that it would be possible in the majority of cases to assign an approximate time for the observation, from the sketch alone. As at Cape Evans, the tendency is for the aurora to originate in a glow low down on the horizon (at a distance), the aurora gradually approaching the station and sometimes passing overhead.

A very fine example of the recurrence of aurora in the same form at the same hour on successive days is furnished by the observations and sketches at 8 hours between June 7th and June 15th. During this period, an aurora of very distinctive form was often seen at 8 hours (never at other times), which took the form of an arch running from the horizon in the south-eastern quadrant up to the zenith. At the zenith the arch then broke into three or four short branches in the north-western quadrant. A description of the form of the aurora during this period is given below, the observations being made at 8 hours precisely :—

At 8 hours on the 7th, the straight portion of the arch ran from E.S.E. to the zenith, thence branching into three short portions in the N.W. quadrant.

At 8 hours on the 8th, the straight arch ran from S.E. to the zenith, thence branching into four arms covering the sector North to S.W. On the 9th, two small streamers were seen close to the zenith, while on the 10th, the form was similar to that on the 8th, but with only two branches in the sector W. to N.W. Again, on the 11th, the display was confined to two small streamers in the north. On the 12th, the straight portion of the arch was very rudimentary, and represented by a streamer in the S.E., the branches being represented by three streamers in the N.W. quadrant. The aurora on the 13th was almost exactly of the same form as on the 12th.

On the 14th, it was cloudy, but on the 15th, four complete branches were again seen in the N.W. sector, the arch from S.E. to the zenith being somewhat incomplete, but quite recognizable as such.

Another striking example of this tendency is supplied by the observations at 4 hours on the 30th May and succeeding days, a distinct tendency being revealed towards the formation of an aurora in the form of a closed oval-shaped curve.

4. Trend and Rotation of Arches.

An analysis of all the arches observed during the year at the Cape Adare station is given in Table 9, which shows also the times at which the arches were seen. As in

Table 9.—Trend of Arches at Cape Adare, 1911.

Trend.	No. of Observations.	Cape Adare Times of Occurrence.
N. to S.	2	1.30, 2.
N.N.W. to S.S.E. ...	14	20, 1, 2, 2, 2, 3, 4, 4, 4, 4, 4, 4, 4.15, 6.
N.W. to S.E. ...	33	18.30, 18.55, 19, 19.55, 23.30, 2, 2, 2, 2.40, 3, 3.30, 3.40, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4.20, 5, 6, 6, 6, 6, 6, 8, 8, 8, 8.
W.N.W. to E.S.E. ...	10	18, 18.25, 20, 24, 3, 3, 3.45, 4, 4, 8.12.
W. to E.	16	15.25, 15.30, 19.45, 20, 21.40, 22.45, 23, 24, 24, 2, 4.15, 4.15, 6, 6, 8, 8.30.
W.S.W. to E.N.E. ...	2	18.30, 6.
S.W. to N.E.... ...	1	18.55.
S.S.W. to N.N.E. ...	1	20.55.

the case of the Cape Evans observations, there appears to be a tendency for the chief points of the compass to be favoured at the expense of the subsidiary points. Making due allowance for this tendency, it appears that arches are most likely to form in a direction N.W. to S.E., or more probably, N.W. by W. and S.E. by E. It will be seen that there is a most marked tendency for the arches to avoid the direction which would bring them into the south-western quadrant, which is the quadrant in which auroræ are rarely seen at this station. Reference to the Cape Evans observations shows that in both cases the most likely trend for arches is in a direction at right angles to the azimuth in which auroræ are least frequently seen.

Again no definite evidence can be offered as to whether the arches show a rotation with the sun or no. A scrutiny of the results shows simply that the rotation, if existent, is more likely to be with the sun than in the opposite sense. There appears to be little tendency for the arches to exhibit the same trend twice daily, as postulated by Mawson for the Ross Island auroræ, except *possibly* in the case of the arches showing a N.W. to S.E. trend.

5. Distribution of Aurora in Azimuth.

Table 10 has been drawn up to illustrate the distribution of aurora both in azimuth and time, the totals for all hours of the day being shown in the last line. The period covered by this Table is May 26th to July 31st, observations only at the regular times of observation being included. From the Table and from fig. 4, it will be observed that there is a well-marked variation in azimuth, the azimuth of

Table 10.—Distribution of Aurora in Azimuth and Time, Cape Adare, 1911.

Hour (Local Time).	N. to N.E.	N.E. to E.	E. to S.E.	S.E. to S.	S. to S.W.	S.W. to W.	W. to N.W.	N.W. to N.	Number of Occurrences in all Sectors.	Number of Observations.
2 hours ...	20	14	18	20	12	12	18	25	139	32
4 ,, ...	24	23	25	25	14	13	17	28	169	35
6 ,, ...	16	14	14	17	16	16	21	22	136	31
8 ,, ...	8	9	12	10	6	9	17	14	85	25
16 ,, ...	8	4	2	0	0	0	2	8	24	9
18 ,, ...	18	4	2	2	1	1	5	12	45	21
20 ,, ...	26	16	8	7	4	3	9	25	98	29
22 ,, ...	19	4	2	0	0	0	5	16	46	25
24 ,, ...	19	7	6	6	5	7	9	19	78	24
Totals ...	158	95	89	87	58	61	103	169		

minimum frequency of aurora being slightly to the south of south-west. These figures are very closely proportional to the corresponding figures for a period May 26th to June 30th, the relative order in frequency of the various sectors being the same in both cases. As in the case of the Cape Evans observations, the "maximum" and "minimum" azimuths are consistently located in nearly the same sectors at all hours, except for the minimum azimuth at 6 hours, which is in the east. This hour is, however, remarkable in that neither maximum nor minimum azimuth is very clearly shown. As will be seen later, the time when auroræ are most likely to be seen at high altitudes (the hour at which aurora is most likely to be reported simultaneously in all sectors) is also near this time.

As at Cape Evans, auroræ are seen in the sectors of maximum frequency even at times when auroræ are least likely to occur, appearing in the minimum sectors, however. only at times of extensive display.

6. Distribution of Aurora with respect to Time.

The analysis of all observations at Cape Adare with respect to both azimuth and time has been shown in Table 10. As before, it will be seen that for almost all hours of the day, the distribution of aurora in azimuth is the same as for the whole day. Further, in each sector, there is evidence of two maxima with a minimum between them at about 22 hours. Usually, the chief maximum is at 4 or 6 hours, with the subsidiary maximum at 20 hours, though in the case of the sector N. to N.E., the relative importance of the two maxima is reversed. Another point which seems to be of interest is the fact that the morning maximum occurs somewhat later in the sectors lying between south and north-west. Though the evening maximum is usually less pronounced than the morning one, it is certainly very definitely indicated. It will be observed that in the evening the number of auroræ between north-east and north-west is generally greater than in all other sectors combined, though this is far from the case during the morning hours.

As in the case of the Cape Evans observations, the last two columns give the number of occasions on which auroræ were seen in any sector, and the number which is the sum of all the numbers referring to the various sectors. The figures in the penultimate column, therefore, correspond to the figures in the last column weighted by a number representing in some measure the extent of the aurora. Though both chief and subsidiary maxima are indicated in both columns, the maxima are most pronounced in the penultimate column, indicating that at times of maximum frequency of aurora, the aurora is also of greater extent.

7. Diurnal Frequency of Different Types of Aurora.

(a) *Auroræ of* 70° *Altitude or over.*

In the period May 26th to July 31st, auroræ were seen on 148 occasions at an altitude of 70° or over. The analysis of these observations, which includes all observations during this period (not only those at even hours), shows a most definite maximum in the period 2–4 hours, an even more striking maximum between 18 and 20 hours (though of smaller amplitude), followed by a very definite minimum between

20 and 22 hours. The results are tabulated in Table 11. Bernacchi, however, states* that at Cape Adare the maximum display in 1899 was at 9 p.m.

TABLE 11.—Distribution in Time of Auroræ, 70° Altitude and over, Cape Adare, 1911.

Two-hourly period ending	2 hrs.	4	6	8	10	12	14	16	18	20	22	24
No. of observations	23	39	23	12	1	0	0	4	3	25	4	14

(b) *Auroræ in the Sectors South to West.*

A similar analysis of the occurrence of auroræ in the minimum sectors is shown in Table 12, only the most definite occurrences being considered, *i.e.* occurrences at altitudes of 80° or less. Again, two maxima and one minimum are seen at approximately the same times as for auroræ in the zenith. The maxima and minimum are, however, not very well marked, and there seems a tendency for the morning maximum to occur later in the day.

TABLE 12.—Distribution in Time of Auroræ in S.–W. Quadrant, Cape Adare, 1911.

Two-hourly period ending	2 hrs.	4	6	8	10	12	14	16	18	20	22	24
No. of observations	8	13	15	2	0	0	0	0	0	9	5	10

(c) *Coloured Auroræ.*

Mention was made of colour (chiefly green), in describing the aurora, on 210 occasions during the months March to September, the number of occasions on which colour was mentioned at the different hours being given in Table 13. In this Table,

TABLE 13.—Distribution in Time of Coloured Auroræ, Cape Adare, 1911.

Two-hourly period ending	2 hrs.	4	6	8	10	12	14	16	18	20	22	24
No. of observations, March to September	17	25	27	5	1	0	0	4	21	44	36	30
No. of observations, May to July ...	17	22	23	5	1	0	0	4	18	31	16	22

the last line gives the corresponding figures for the three darkest months only, viz., May, June, and July. Again, a maximum is shown in the morning at about 6 hours, with another maximum (of greater amplitude in this case) at 20 hours. It will be observed, however, that the usual minimum between 20 and 22 hours is not shown in the case of the longer period, though fairly well marked for the three darkest months only. This difference between the two periods seems to be due to the fact that, both in August and September, there were more occurrences of auroræ between 20 and 22 hours than between 18 and 20 hours, no doubt due in part to the fact that

* "National Antarctic Expedition, 1901–1904," 'Physical Observations,' p. 100.

twilight conditions obtain during these months for the greater part of the 24 hours. This cannot, however, be the only cause, as the observations between 22 hours and 24 hours during these months are less numerous than between 20 and 22 hours. There is thus some indication that during August and September, the afternoon maximum for coloured auroræ may occur later than during the previous three months. During these two months, as well as in March and April, there were very few occurrences of coloured auroræ in the morning hours (only seven in all).

(d) *Diurnal Frequency of "Glow" Auroræ.*

Table 14 shows the daily variation in the occurrence of "Glow" auroræ during the period May 26th to July 31st, using all the available data (not only the observations at even hours).

TABLE 14.—Distribution in Time of "Glow" Auroræ, Cape Adare, 1911.

Two-hourly period ending	2 hrs.	4	6	8	10	12	14	16	18	20	22	24
No. of occurrences...	22	19	8	1	0	0	0	4	14	20	22	12

The most interesting feature brought out in this Table is that "Glows" are almost equally likely to occur at all hours between 18 hours and 4 hours, at which time a minimum is shown. As glows may be seen and logged independently of any other forms of aurora, it is not strange that no very definite connection is shown with the diurnal frequency of other types.

Diurnal Frequency and Brightness of Auroræ.

To ascertain whether the diurnal frequency is dependent upon the brightness of the aurora, Table 15 has been formed, showing the number of occasions (during the

TABLE 15.—Diurnal Frequency and Brightness of Aurora, Cape Adare, March to September, 1911.

Two-hourly period ending	Brighter Auroræ. A	Fainter Auroræ. B	"Clear, no Aurora." C
2 hours	12 (12)	27 (23)	(12)
4 ,, ...	27 (21)	21 (19)	(4)
6 ,, ...	11 (10)	28 (21)	(4)
8 ,, ...	2 (1)	27 (24)	(8)
10 ,, ...	0 (0)	5 (5)	(3)
16 ,, ...	3 (2)	7 (7)	(10)
18 ,, ...	7 (5)	25 (15)	(17)
20 ,, ...	35 (23)	30 (16)	(15)
22 ,, ...	28 (10)	32 (18)	(18)
24 ,, ...	23 (12)	27 (22)	(13)

Figures for the period May 26th to July 31st are shown in brackets.

whole period of observation) on which the brighter and fainter auroræ were seen at different times of day. In brackets are also shown the corresponding figures for the period May 26th to July 31st. The third column gives the number of occasions on which "Clear, no aurora," was logged at exact even hours, during the shorter period.

From the Table it will be seen that, for the period May 26th–July 31st, the brighter auroræ show the early morning and evening maxima quite well (2–4 hours and 18–20 hours, respectively), the minimum at 20–22 hours being not well marked. The situation is quite otherwise with auroræ of lesser brightness, which are fairly evenly distributed over the dark period of the day, a distribution somewhat similar to that of "Glow" auroræ.

It will further be observed that the inclusion of days in March, April, May, August, and September, does not modify the distribution to any great extent.

It might seem from consideration of these figures that the brighter auroræ occur most frequently at times when the aurora is close to the zenith (4 hours), a result which is reversed at the Cape Evans station (compare Table 8). Though Table 15 shows almost equal numbers of auroræ in the morning and evening periods, this is far from true for the auroræ classed as "bright" and "very bright," three times as many being recorded in the evening as in the morning period. This shows that the brightest auroræ rarely do occur at Cape Adare at times when auroræ are most frequently seen near the zenith, a result in direct opposition to that deduced from a division of the aurora into only two classes of brightness. On the other hand, *very* faint auroræ are most likely to be seen in the morning hours.

Another interesting result of closer analysis of the available figures shows that bright auroræ are very rare in the late morning, while faint auroræ are comparatively very common. This result one would be inclined to explain as due to an incorrect estimate of the influence of the twilight arch in the late morning. If this were the case, however, it would be expected that a similar effect would be shown in the corresponding early hours of the afternoon. For the class of very faint auroræ, this is not the case, which lends strength to the contention that there is a real difference between the diurnal variation of bright and faint auroræ.

As in the case of the observations at Cape Evans, the ratio C/(A+B) (in Table 15) varies during the day—from 0·1 between 2 and 4 hours, to 1·1 at 16 hours.

GENERAL DISCUSSION OF AURORAL OBSERVATIONS.

Before proceeding to a discussion of the correspondence between magnetic disturbances and auroral displays, it is advisable to review the data before us and to see if the conclusions are in agreement with those which have been drawn from observations on the Aurora Borealis.

Though the aurora was seen much less frequently at Cape Evans than at Cape Adare and was at the former station much less brilliant, there is considerable similarity between the two sets of observations. In both cases, the aurora showed a striking partiality for certain sectors combined with an even stronger tendency to avoid other sectors. At Cape Evans, the maximum is in the E.N.E. and the minimum in the west; at Cape Adare the maximum is in the north and the minimum in the S.W.; in each case, the angle between the two, measured through east, is slightly more than 180°.

In each case, the aurora first appears in the "maximum sector," *i.e.* the sector in which it is most frequently seen, gradually approaching the station, and sometimes passing overhead and disappearing in the direction of the "minimum sector." At Cape Evans, the aurora passes overhead infrequently, and is seen in the "minimum sector," or sector in which it is least frequently seen, only rarely. The trend of the arches is fairly constant at both stations, but particularly so at Cape Adare, and in both cases the direction of movement is from the "maximum sector" to the "minimum sector," the direction of movement being also at right angles to the trend of the arch.

At both stations, the average time of occurrence in the "minimum sector" is somewhat later than the average time of occurrence overhead.

The time at which the aurora passes overhead is, in the case of Cape Evans, at 5 hours (time of 180th meridian), and in the case of Cape Adare, at 4 hours (local time). The occurrence in the zenith is, therefore, almost simultaneous at both stations, though these are separated by some 6 degrees of latitude.

Not unnaturally, the time at which the aurora is most frequently seen overhead is also the time at which aurora is most frequently seen.

At Cape Adare, a secondary maximum occurs at 20 hours, followed by a minimum at 22 hours, both of which are most clearly marked in auroræ seen close to the zenith, and in bright and coloured auroræ. Traces of a secondary maximum and the following minimum are also seen at Cape Evans, but not so clearly, though the occurrences of brilliant auroræ are more frequent in the afternoon than the morning, a result we have already suggested as indicative of a real difference between the character of the morning and evening maxima. It is interesting also to note that the minimum which immediately follows the Cape Adare maximum is a very sharp one, followed by a sharp recovery at midnight.

A study of Table 10 seems to indicate that, at Cape Adare, the main body of the aurora did not pass over the station during the evening maximum, but remained to the north of the station, the aurora approaching the station only rarely at this time, but occasionally moving over into the minimum sector. Cape Evans being closer to the magnetic axis of the earth was affected even more rarely, so the secondary maximum is merely indicated, probably corresponding to periods of great brilliancy of aurora. (As will be seen later, magnetic disturbances at the station and brilliant auroræ are most likely to coincide in the afternoon, not at times when the aurora is most likely to be overhead, or closest to, the station.)

Further indication of the striking daily period is given by the recurrences of auroræ at the same hour on successive days, sometimes even of the same form.

Qualitatively, it seems that the auroral phenomena are well explained on the theory due to the successive labours of Professors Birkeland, Störmer and Vegard. On this theory, the aurora is caused by charged particles emanating from the sun, their paths being deflected by the earth's magnetic field, causing them to fall chiefly in an "auroral belt" distant about 20° from the point where the earth's magnetic axis cuts the earth's surface. At any instant, the auroral belt* should take the form of a spiral directed towards this point. Due to the earth's rotation about its axis, this spiral sweeps above the earth, with "centre" approximately fixed over the point where the magnetic axis cuts the earth's surface. A brilliant exposition of the theory has been given by Professor Vegard,† who, at the same time, presents evidence for his contention that the solar particles causing the aurora are positively charged and similar to the alpha particles (charged helium atoms) which are due to radio-active disintegration.‡

In any case, there can be little doubt that the particles causing the Aurora Australis are the same as those to which the Aurora Borealis owes its origin and that, therefore, the height at which the particles lose their charge and cause the most intense ionisation will probably be the same in the South as in North Polar regions. If we assume the same height (85 to 160 km. from the earth's surface, on the average), it will be evident that the same aurora can be seen both from Cape Adare and from Cape Evans.

From the observations of only two stations, it is clear that little evidence can be adduced for or against a theory based on many years' experiment and observation in northern latitudes. Of the evidence which can be offered, the data relating to the

* The auroral belt being defined as an area between two curves whose centre is above the point where the magnetic axis cuts the earth. Auroræ will be seen by observers outside this belt, but most frequently by an observer in this belt and distant about 20° from the magnetic axis. At any moment the aurora is spread in space along a broad curve, which represents the sum of all the spiral paths of particles projected with different velocities, or particles which have travelled from the sun by different paths. This broad curve can, for convenience, be called the "auroral spiral."

† L. Vegard—"Bericht über die neueren Untersuchungen am Nordlicht." 'Jahr. d. Radioactivität und Electronik,' XIV, 4, Dec., 1917.

‡ Vegard has later abandoned his contention that the rays are positively charged alpha rays—'Geofysiske Publikationer,' Vol. I, No. 1.

trend of arches appears to be the most definite. The constant N.W.–S.E. trend at Cape Adare is associated with the passage overhead of the "auroral spiral." That portion of the spiral which passes above Cape Evans is, however, much less constant in direction (N.–S.), and there is a suspicion, at least, of a change in direction (anti-clockwise rotation) with time. This part of the spiral is therefore closer to the centre where the spiral is more strongly curved and possibly more variable in curvature on successive days.

The fact that the spiral lies overhead both stations at about the same time in the morning gives (not very convincing) information as to the form of the auroral spiral in these latitudes.

A natural consequence of this theory is that, for stations in equal magnetic latitudes,* the aurora should pass overhead at the same magnetic local time, where the magnetic local time bears the same relation to the magnetic axis, as does local time to the rotation axis of the earth.

The results of observations in the northern auroral zone are similar to those described above in that two maxima, one in the evening and one in the morning, are found, with a more or less pronounced minimum between. The strongly coloured, quickly moving and brilliant auroræ are more frequent in the afternoon than in the morning, while the reverse is true for faint auroræ.† We have, therefore, considerable support for suggesting that the secondary (afternoon) maximum is of quite a different type to the morning maximum and is probably connected with brilliant auroræ and possibly (as will be seen later) with magnetic disturbances. Thus, the morning maximum seems to be a frequency maximum, and the afternoon maximum an intensity maximum.

In the foregoing, the occurrences of "clear, no aurora," have not been considered, but an examination of the diurnal variation is not without interest. As the chief auroral maximum occurs at both stations in the morning, we should naturally expect the fewest occurrences of "clear, no aurora," at this time, with the maximum frequency at the time of minimum auroral frequency in the afternoon. This is indeed the case at the Cape Adare station, though only the morning minimum is well marked. At Cape Evans also, a minimum occurs in the morning at 4 to 5 hours, with a maximum in the evening at 22 hours, though neither are well defined.

It is of great interest to note that the relative number of observations of aurora and of "no aurora" at Cape Evans in the years 1911 and 1912 were the same, notwithstanding the fact that the number of sunspots observed in 1912 was considerably less than in 1911. This argues that the presence or absence of auroræ viewed from the Cape Evans station may be nearly independent of the sunspot frequency. This is reasonable on the view that, apart from the intensity maximum in the afternoon, the presence or absence of aurora is largely independent of spots on

* The magnetic latitude bears the same relation to the earth's magnetic axis as does the astronomical latitude to the earth's rotation axis.

† L. Vegard, *loc. cit.*

the sun and chiefly conditioned by the actual distance of the observing station from the centre of the auroral zone. There seems, in fact, little doubt that aurora would be seen *almost continuously* during the winter from a position a little to the north-east of Cape Adare. Evidence for the pronounced daily variation in the occurrence of auroræ has already been given, and there appears to be a great probability that auroræ can be seen from *some* spot on the earth's surface at every instant.

Since magnetic storms are of comparatively infrequent occurrence at low latitudes, we cannot expect to find a very close relationship between the occurrence of auroræ at high latitudes and the incidence of magnetic storms of world-wide extent. On the other hand, we know that there is a fairly close connection between such storms and the appearance of auroræ at low latitudes.

On Vegard's theory that the aurora is caused by rays projected from the sun, and similar in every way to the rays which accompany radio-active disintegration, we can recognise that the normal path of each ray will be a spiral, (the curve which represents the total of all these paths being the "auroral spiral"); the time at which one portion of this spiral appears overhead at each station is in the early morning; there is a tendency for a second maximum to appear overhead in the afternoon, and this tendency does not appear to be quite a normal one.

If the particles causing the aurora are alpha particles due to radio-active changes taking place in the sun, we must also recollect that a series of radio-active changes will be accompanied by beta and gamma rays, also projected from the sun.* Both of these are more penetrating than alpha rays, the former being negatively charged and more easily deflected in a magnetic field, and the latter being short wave radiations which are not so deflected.

Auroræ and Magnetic Disturbances.

It has long been known that, in low latitudes, there is a direct relation between auroral phenomena and magnetic storms.

Though at low latitudes, auroral displays are accompanied by magnetic storms, this is by no means always the case in high latitudes, and as Dr. Chree has pointed out in the Magnetic Report of this Expedition, the same holds true at the Cape Evans station.

Dr. Chree has, however, shown that, *on the whole*, the magnetic character of the hour is definitely related to the brilliancy of the aurora during that hour. This result is of great interest and demands the fullest investigation.

* The projection of particles bearing positive and negative charges in significantly equal numbers is a necessary condition, as pointed out by Vegard.

Auroræ and Magnetic "Character."

As pointed out by Dr. Chree,* there is a distinct relation between the "magnetic character" at Cape Evans and the brilliance of the auroræ observed at the same hour from that station. The following figures for auroræ of Classes I to IV, arranged in descending order of brightness, are given below :—

Cape Evans, 1911.—Class I.	Mean	magnetic	character	number	1·28.
,, II.	,,	,,	,,	,,	1·06.
,, III.	,,	,,	,,	,,	0·93.
,, IV.	,,	,,	,,	,,	0·66.

Mean character number for May–August, 0·84.

Cape Evans, 1912.—Class I.	Mean	magnetic	character	number	0·93.
,, II.	,,	,,	,,	,,	0·63.
,, III.	,,	,,	,,	,,	0·71.
,, IV.	,,	,,	,,	,,	0·25.

Mean character number for May–August, 0·72.

Though the variations in mean character number are not intrinsically large, we must recollect that these figures refer to only a portion of the whole time, periods of bad weather and daylight being excluded. In these circumstances, it is not surprising that the mean for the whole of the winter months† is higher than the mean for very faint auroræ. It is, in fact, fairly clear that the correlation between auroræ and magnetic character number is not close, except possibly for auroræ of exceptional brilliance.

We had a definite impression while in the Antarctic that the correspondence between auroræ and magnetic disturbances was closest in the case of coloured auroræ and those which showed much movement. That this impression is justified is shown when we take from Dr. Chree's figures the character numbers corresponding to the few cases when mention was made of much movement, or of colour, in the aurora log.

The figures for these two classes at Cape Evans in 1911 are :—

Coloured auroræ	Mean	character	number	=	1·82.
Auroræ with much movement	,,	,,	,,	=	1·44.

As mentioned before, it is interesting to note that the greater number of both these classes were recorded in the afternoon, a result which equally applied to the auroræ of Class I.

* "British Antarctic Expedition, 1910–1913," 'Terrestrial Magnetism,' Chap. XIV. The magnetic character number of a day or an hour is a number (between 0 and 2) which gives a measure of the degree of magnetic disturbance during that period. Maximum disturbance is marked 2, and minimum disturbance, 0.

† The mean for the same period, but excluding the daylight hours, would be lower.

Brilliant auroræ appear, therefore, to occur most often near the time of the secondary auroral maximum, at which time there is at least a suggestion of a secondary maximum for the mean magnetic character number during the winter months. As may be seen from Dr. Chree's figures for the winter months,* this secondary maximum for magnetic character number is at 19–20 hours, the mean value at 4 hours being low and the chief maximum at about 9 hours. We therefore infer that the occurrence of auroræ close to, or over, the station in the morning does not (on the whole) correspond with more disturbed magnetic conditions at the same station, but with less disturbed conditions.

The secondary maximum in magnetic character number occurs only in the winter months and seems, according to Dr. Chree, to be associated with short disturbances of a "special type."† One is tempted, therefore, to infer that the secondary auroral maximum is also associated with these special magnetic disturbances and with the occurrence of brilliant, coloured or quickly moving forms, appearing at a time when auroræ are rarely seen. Such an inference is hardly justified on the scanty evidence to hand, though a correspondence between secondary maximum and type of disturbance seems to be indicated, both as regards magnetic and auroral characteristics, while the relation between magnetic character number and auroral intensity, on the one hand, and between the "special type" of magnetic disturbance and the strongly coloured and quickly moving forms of aurora, on the other hand, is very slightly indicated. The whole relation between magnetic and auroral disturbances, as will be seen later, may be stated as follows:—

(i) A fairly strong correspondence between *periods* of disturbed auroral and magnetic conditions, particularly in the stronger disturbances.

(ii) A *slight* correspondence between disturbed conditions of both types *in the same hour*.

(iii) A possible secondary maximum in the mean character number for disturbance, of both types, occurring about the same time in the afternoon, in both cases. (The secondary maximum in mean magnetic character number seems to be connected with magnetic disturbances of the "special type," while the secondary auroral maximum seems to be connected with the occurrence of brilliant, coloured and quickly moving auroræ.)

Even if we admit that there is a real correspondence between magnetic and auroral disturbances, no deduction can be drawn as to whether the magnetic disturbances in the evening are directly caused by the particles to which the aurora is due, or whether the auroral display at this hour is due to a change in the curvature or

* *Loc. cit.*, Table LXXX; also p. 143.

† *Loc. cit.*, pp. 270 and 143.

position of the spiral in space (due to variation in the magnetic forces), causing the aurora to be seen overhead at a time when it is normally far north of the station. Quite possibly the two are associated through a common cause.

It is necessary to examine more closely the relation between mean magnetic character number and type of aurora, and, with this object, the mean magnetic character numbers for hours when auroræ were seen close to the zenith and in the sectors where they were least frequently observed have been calculated from Dr. Chree's figures, together with the corresponding number for all observations of "clear, no aurora," at the exact hours. The figures for 1911 are as follows :—

Auroræ in the zenith	Mean character number,			0·88.
Auroræ in the sectors where they were infrequently observed ..	,,	,,	,,	0·87.
"Clear, no aurora"	,,	,,	,,	0·75.

These three numbers differ little from one another and from the general means and confirm the conclusion that the position of an aurora has little, if any, effect on the mean magnetic character number. The figure corresponding to the large number of occurrences of "clear, no aurora," confirms our conclusion that the correlation between magnetic character number and auroræ is not close except for brilliant, coloured or quickly moving forms.

The fact that the position of the aurora bears little relation to the magnetic character number is clearly proved by the figures given by Dr. Chree for the Cape Adare auroral observations. These figures are reproduced below for four classes of auroræ arranged in descending order of brightness, the corresponding magnetic character numbers being taken from the Cape Evans magnetic traces some hundreds of miles distant.

Cape Adare, 1911.—Class	I.	Mean magnetic character number (Cape Evans)						1·32.
,,	II.	,,	,,	,,	,,	,,		1·22.
,,	III.	,,	,,	,,	,,	,,		1·00.
,,	IV.	,,	,,	,,	,,	,,		0·87.

Mean character number, May–August, 0·84.

It will be seen that there appears to be a closer correspondence between auroral intensity at Cape Adare and magnetic character number at Cape Evans than was the case with auroral observations at Cape Evans. This increased correspondence is, however, probably accounted for by the more favourable meteorological conditions and by the fact that the aurora at Cape Adare was of such intensity that the presence of moonlight was insufficient to render observations impossible.

As in the case of the Cape Evans observations, mean character numbers corresponding to various types of aurora have been compiled and are shown below :—

Coloured auroræ, Cape Adare	..	Mean	magnetic	character	number,	1·20.
"Clear, no aurora," ,,	..	,,	,,	,,	,,	0·75.

From the above figures, it seems fairly clear that periods of brilliant and coloured auroræ are definitely related, *on the average*, to magnetic disturbances at the same station, and that the same relation can also be definitely traced between auroræ and magnetic disturbances as far apart as Cape Evans and Cape Adare.

As magnetic disturbances (when their occurrence can be traced at a number of magnetic stations) appear to occur simultaneously, or almost simultaneously, over the earth, we might expect to find that increased brilliancy of auroral display would also occur simultaneously. This increased brilliancy might, however, only be observable at certain favoured places, especially if increased brilliancy were associated with some displacement of the paths of the individual spirals as they approached the earth. We might, therefore, expect a closer correspondence between auroral intensity and magnetic character number if simultaneous auroral data were available from a number of widely separated stations, particularly if due account was taken of the normal intensity of aurora at the hour in question. Though we cannot state definitely that a brilliant auroral display may not occur *somewhere* for every magnetic disturbance, there seems to be no doubt that *every* striking auroral display in high latitudes is *not* associated with a simultaneous magnetic disturbance. The correlation between auroræ and magnetic disturbance cannot therefore be complete, suggesting that the magnetic disturbances may not be due to the same particles, which give rise to the aurora ; they might, however, be due to similar particles which do not converge towards the magnetic axis of the earth.

Mention has previously been made of the fact that auroral displays show a tendency to continue for long periods, and the same is true, in some degree, of magnetic disturbances. It is, therefore, very necessary to examine the magnetic conditions preceding and following the hour of maximum auroral display, to determine if the correspondence is a real one, and to make certain that the maximum of the mean character number is simultaneous with the greatest intensity of aurora. This analysis is all the more necessary if we recollect that the production of alpha rays by radio-active disintegration in the sun must be accompanied by the production of beta and gamma rays. All of these rays travel with different velocities and therefore should reach the earth's atmosphere after different intervals of time.

The necessary reductions have been made completely for 1911 in Classes I, II, III and IV of auroræ seen at Cape Evans, and in Classes I and II of auroræ seen at Cape Adare. These figures are given below in Table 16 and shown in diagrammatic form in fig. 4. In this Table, $(n-1)$ and $(n+1)$ represent, respectively, one hour before and one hour after the time corresponding to the occurrence of auroræ of the class mentioned.

TABLE 16.—Relation between Auroral Intensity and Mean Magnetic Character Number.

Cape Evans, 1911.

	Mean Character Number.								
	($n-4$)	($n-3$)	($n-2$)	($n-1$)	n	$n+1$	$n+2$	$n+3$	$n+4$
Class I	—	—	1·05	1·16	1·28	1·22	1·11	—	—
,, II	1·00	1·00	1·02	1·07	1·08	1·03	·98	·95	·95
,, III	·90	·89	·89	·90	·92	·89	·90	·88	·92
,, IV*... ...	·63	·57	·64	·66	·66	·61	·63	·70	·71

Cape Adare, 1911.

	Mean Charaeter Number.						
	($n-3$)	($n-2$)	($n-1$)	(n)	($n+1$)	($n+2$)	($n+3$)
Class I	1·08	1·15	1·32	1·42	1·32	1·15	—
,, II	1·06	1·13	1·22	1·21	1·08	1·04	1·04

This Table (and figs. 5 and 6) shows most clearly that, in the case of auroræ of the first two classes (brightness above normal), there is a real relation between brightness of aurora at a station and mean magnetic character number at the same station in the same hour, the correlation between character number and brightness of aurora being greater, the greater the auroral intensity, but inappreciable for aurora of less than average brightness.

The Table further brings out the point that the maximum mean character number at Cape Evans occurs at about the same time as the maximum of bright auroræ at Cape Adare, some 400 miles distant.

Fig. 5 shows most clearly that the correspondence between even the brilliant auroræ and magnetic disturbance at the same hour is slight in comparison with the correspondence between *periods* of brilliant auroræ and *periods* of magnetic disturbance. Though there is a real correspondence between the two types of disturbance of the lowest classes, this correspondence is not particular, but general, and refers to the period, not to the particular hour of observation.

* The figures in this class are too few to give a good mean character number. In the case of the Cape Adare observations, it has been assumed that local time at Cape Adare and time of the 180th meridian differed by exactly 1 hour; if the maximum auroral display coincided with maximum magnetic disturbance, the mean character number would be greatest between hours (n) and hours ($n-1$).

A closer analysis of the coincidence of auroræ with hours of high and low magnetic character is not without interest. With this object, Table 17 has been formed for three classes of auroræ—above normal brightness, below normal brightness and " no aurora "—showing the coincidence with hours of magnetic character 1·5 or 2 and of magnetic character 0, for different hours of the day, the numbers referring to the latter being shown in brackets.

TABLE 17.—Relation between Auroral Intensity and Magnetic Character at Cape Evans, 1911.

Number of Observations with Magnetic Character 2·0 *or* 1·5 *and Number of Observations with Magnetic Character* 0 (*in brackets*), *at exact hours only.*

Hour ending	Aurora of Brightness		" Clear, no Aurora."
	Above normal.	Below normal.	
1	7 (2)	2 (4)	7 (13)
2	6 (3)	5 (4)	5 (11)
3	1 (0)	6 (2)	3 (12)
4	1 (8)	4 (6)	3 (8)
5	4 (1)	7 (5)	3 (9)
6	2 (2)	4 (6)	6 (5)
7	0 (1)	6 (4)	6 (3)
8	4 (1)	2 (0)	3 (2)
9	2 (0)	0 (4)	1
10	2 (1)	0 (1)	0
11	0 (1)	1 (2)	0
12	0 (1)	0 (0)	0
13	1 (2)	0 (0)	0
14	0 (0)	0 (0)	0
15	1 (0)	0 (1)	1 (3)
16	2 (0)	0 (2)	1 (4)
17	1 (0)	1 (0)	4 (5)
18	5 (3)	2 (0)	6 (6)
19	4 (1)	1 (0)	7 (7)
20	3 (0)	4 (1)	14 (9)
21	4 (0)	1 (0)	9 (13)
22	5 (0)	4 (1)	11 (17)
23	7 (0)	4 (2)	8 (11)
24	9 (2)	3 (3)	9 (11)
Totals	71 (29)	57 (48)	107 (149)

As might be expected, the sums of the two numbers in each class, corresponding to magnetically disturbed and quiet conditions, show a diurnal variation similar to that shown in Table 8, which is derived from all hours.

It is in the afternoon that auroræ are most likely to correspond with magnetically disturbed hours and in the morning that auroræ are most likely to be seen during magnetically quiet hours.

Remarks.

From a survey of the auroral material gathered both from Arctic and from Antarctic regions, it does not appear that any very great advance in our knowledge is likely to accrue from direct observations of auroræ at isolated stations, unless magnetic data are available for comparison. It appears, in fact, as if the chief advance in our knowledge regarding auroræ is likely to be made through a searching study of the causes of magnetic disturbances, and it is certainly difficult to escape the conclusion that these disturbances owe their origin to charged particles projected from the sun. It seems particularly desirable to emphasise the fact that there is no indication of the successive arrival of negatively and positively charged particles* in the earth's atmosphere, the maximum magnetic and auroral disturbances in Polar regions occurring at about the same time, on the average.

It does not seem out of place to emphasise the fact that striking auroræ can be seen in the auroral zone without the occurrence of a corresponding magnetic disturbance, particularly in the early morning, the closest correlation between magnetic disturbances and auroræ being in the late afternoon. It is certainly interesting to note that the general maximum of magnetic disturbance falls not far from magnetic local noon, the secondary maximum near magnetic local midnight appearing only during the winter months.

It is necessary to bear in mind that it is not essential for a *local* auroral display, however striking, to give rise to a magnetic disturbance of significant amount, even if the prime cause of the two phenomena is identical. In fact, the magnetic disturbance is likely to depend almost as much upon extent as upon intensity of precipitation of the solar particles.

It is at least open to consideration whether the prime causes of the two phenomena are identical, and it must be admitted that we have every right to assume that auroræ can be seen somewhere on the earth's surface every day, and at every moment of the day. This would demand a continual influx of solar particles from the sun. The magnetic character number corresponding to the occurrence of very faint auroræ is less than the mean of all hours, and this seems to lend support to the contention that the incidence of aurora somewhere in the auroral zone is a continuous phenomenon.

There can be little doubt that the relation between magnetic storms and auroræ exists in virtue of the same or a similar projection of energy from the sun and the possibility exists that it is only in particular circumstances that the particles (which must be charged, in part at least) meet the atmosphere in low latitudes and are accompanied by severe magnetic storms outside the polar regions.

* As pointed out by Schuster and Vegard, positively and negatively charged particles must occur together during the journey in approximately equal numbers if the particles are to reach the earth's atmosphere without dispersion. Vegard also points out that the number of each sign leaving the sun in unit time must be equal.

Evidence has already been given to show that the correlation between magnetic disturbance and auroral display is better, the more intense the auroral display (both in high latitudes), and that this correlation is not so much a correlation at particular hours as a correlation common to the whole disturbed period.

Whether we agree with Vegard in assuming that the solar particles causing auroræ are charged particles due to radioactive disintegration in the sun, or prefer the theory* revived by Lindemann and ascribe them to *clouds* of particles projected from the sun, is not of immediate moment.

The latter theory, as Lindemann points out, is capable of giving an explanation on the quantitative side of the energy involved in a large magnetic storm. On the qualitative side, there is little to choose between the two, but it should prove possible to discriminate between the rival theories if further information were available.

For example, information might without too great difficulty be obtained on the following points :—

(i) The period between the instant when the sunspot faces the earth and the initiation of the corresponding magnetic storm ; the variation of this period (the time taken for the charged particles to reach the earth) with the magnitude and activity of the sunspot and with the duration of the storm.

(ii) The height of the aurora at different (low) latitudes and its dependence upon the activity of the sunspot to which it owes its origin.

(iii) The relation (if any) between the height and intensity of the aurora and its spectrum.

In the process of obtaining this information, it seems not unreasonable to hope that a clear indication would be given of the cause of the earth's permanent magnetism.

Lindemann's theory that the charged particles causing both magnetic storms and auroræ are due to clouds of ionised particles projected from the sun (such as are observed in the prominences), with a velocity due to light pressure on the neutral atoms, is given support by the work of Megh Nad Saha.† The latter points out that, in the chromosphere, ionisation is complete above a certain level, being evidenced by the fact that *only* the "enhanced" lines, which are due to ionised atoms, appear above this level. A rough calculation is made of the height in the chromosphere at which this takes place for selected elements using data on ionisation potential, by application of the "Reaction-isobar" to the process of ionisation. The calculations give figures in rough agreement with the observed heights for several spectral lines, if certain assumptions regarding temperatures and pressures in the chromosphere are made. If, now, selective light pressure acting in opposition to gravity is the cause of the presence of these ionised elements at such high levels, and the velocities imparted in

* Lindemann, 'Philosophical Magazine,' December, 1919.

† 'Phil. Mag.,' October, 1920.

the process of ionisation are sufficient to carry them out of the sun's atmosphere. a direct connection between sunspots and auroræ may exist. The continuous, or almost continuous, influx of charged particles into the earth's atmosphere is thus explicable, a circumstance which is probable, but which is difficult to explain on the older theories.*

[*Note added February*, 1922.—Fleming (in 'Nature,' of February, 1922) discusses the projection of comparatively large charged particles from the sun by light pressure, and the possibility that these will be brought to rest in the earth's atmosphere when the density reaches the critical value at which frictional resistance rises to its normal value.]

* Rayleigh has been able to photograph the green auroral line on most clear nights on these latitudes.

APPENDIX.

NATURAL IONISATION IN CLOSED METAL CONTAINERS.

During the voyage of the "Terra Nova" from Cardiff to Lyttelton, New Zealand, observations of the number of ions formed per second within a vessel of about 27,000 c.cs. capacity were regularly made and the results have been published in the 'Proceedings of the Royal Society,' A, vol. LXXXV, 1911.

The most important results were to show that the number of ions formed per c.c. per second in such a vessel was lower than the number formed on land; that a considerable addition to the normal ionisation over the sea might, under favourable circumstances, be due to radioactive products deposited on the ship and due primarily to a high radium content of air derived from neighbouring land masses; moreover, as in previous experiments on Lake Ontario,* that the value over the sea could not be reduced below a certain limit—in this case 4 ions formed per c.c. per second. A mean value of 3·8 ions has also been observed on the fourth cruise of the "Carnegie."

The question of the lower limit which can be reached is of importance, since the cause of the residual ionisation is still obscure. For this reason a few measurements using the apparatus and method described in the paper cited above were made in 1911 within a cave excavated in a snowdrift consolidated to ice. In this cave the vessel was screened by many feet of ice on all sides, except from radiation coming from above and from the earth. Three feet of ice separated the cylinder from the upper surface of the drift, and one foot of ice from the ground below. It is unfortunate that the opportunity was not taken to measure the radium content of the ice in order to determine whether there was any notable contribution to the ionisation from this cause.† The radium content of the rock was not ascertained, but the surface of the ground had for many years been protected from the deposition of radioactive substances by the ice covering above it. It was thought that, in these surroundings, the residual ionisation might be even less than that which was observed on the "Terra Nova," and this proved to be the case.

The lowest value observed on 14 days in July, 1911, was in fact just over 3 pairs of ions formed per c.c. per second, though considerable variations were observed from day to day. The mean value during the period was almost exactly the same as the lowest observed on the "Terra Nova," viz., 4 pairs of ions formed per c.c. per second.

* Wright, 'Phil. Mag.,' February, 1909 (lowest value 6·0 ions). A later determination by McLennan, using a cylinder of ice over Lake Ontario, gave a value of only 2·6 ions.

† An indication of climatic variations might well be obtained by systematic investigation of the radioactive content of glaciers at different depths.

The variations observed from time to time were, however, considerable, and there is little doubt that the discrepancies must be ascribed to imperfections in the experimental arrangements. The mean temperature in the cave during this period was $-25°$ C., and it may well be that the voltage of the dry cells used to furnish the high potential was subject to variations.

Since the magnitude of the variations (about 100 per cent.) lay far outside the limits of observational error, an opportunity was made in the succeeding winter to investigate this point more closely. For this purpose a hut was constructed of petrol cases lashed together and furnished with a canvas roof, and arrangements made to take an hourly photographic record of the variations. Except for the difficulty in maintaining the clock of the barograph drum at low temperatures and in keeping out drift snow, the arrangement worked satisfactorily until the hut was blown down in a gale, but a record was obtained covering the greater part of the period May 20th to June 9th, 1912. The variations from hour to hour were very large, the largest value observed (in arbitrary units) being 270 and the smallest 119. In view of these variations, it is hardly to be expected that any evidence of a regular daily variation could be traced during such a short period and this is confirmed by a scrutiny of Table 1, which give the mean hourly values of the natural ionisation for this period in arbitrary

TABLE 1.

Hour ending (Time of 180th meridian).	Ionisation (in arbitrary units).
1 hour	189
2 „	186
3 „	183
4 „	195
5 „	190
6 „	193
7 „	188
8 „	188
9 „	186
10 „	191
11 „	184
12 „	187
13 „	193
14 „	195
15 „	193
16 „	194
17 „	209
18 „	192
19 „	189
20 „	188
21 „	196
22 „	187
23 „	201
24 „	180

units, after correction for insulation leakage. The outstanding features of this Table are the high mean values at 5 p.m. (time of 180th meridian) and 11 p.m.

The mean values are given in Table 2. The Table is unfortunately incomplete owing to the omission of days during which observations could not be recorded, but the variations from day to day are clearly of the same magnitude as the mean hourly variations.

On consideration of the values, there seems little doubt the observed variations from hour to hour must be due to imperfections in the experimental apparatus, but there is some evidence that the mean daily values are subject to other variations, which we would be inclined to say were due to radioactive substances derived from the

TABLE 2.

Date, 1912.	Ionisation (in arbitrary units).
May 20	192
21	185
22	188
23	194
24	190
27	198
28	200
29	201
30	203
June 1	183
2	200
3	185
4	178
5	187
6	198
8	179
9	171

air and deposited on the earth. No connection, however, has been traced with the meteorological conditions prevailing during this period, though, somewhat strangely, the mean hourly value associated with northerly winds (193·5) and southerly winds > 15 miles per hour (192·5) is greater than that associated with calms and southerly winds less than 15 miles per hour (185·0). The difference may, however, be accidental, and it is known that the mean radioactive content of the air is slightly lower at high wind velocities, while the mean value is not greatly different from that observed over the ocean.*

If such a variation can be inferred, a question at once arises as to the origin of the radiations causing the variation, in view of the small amount of rock exposed on the Antarctic Continent, the small radioactive content of the air and the time which must elapse during the transfer of products derived from other parts of the earth's

* 'Meteorology,' vol. I, p. 320.

surface to the Antarctic. The question must be left open, but seems to be worthy of experimental investigation when the next opportunity is afforded.

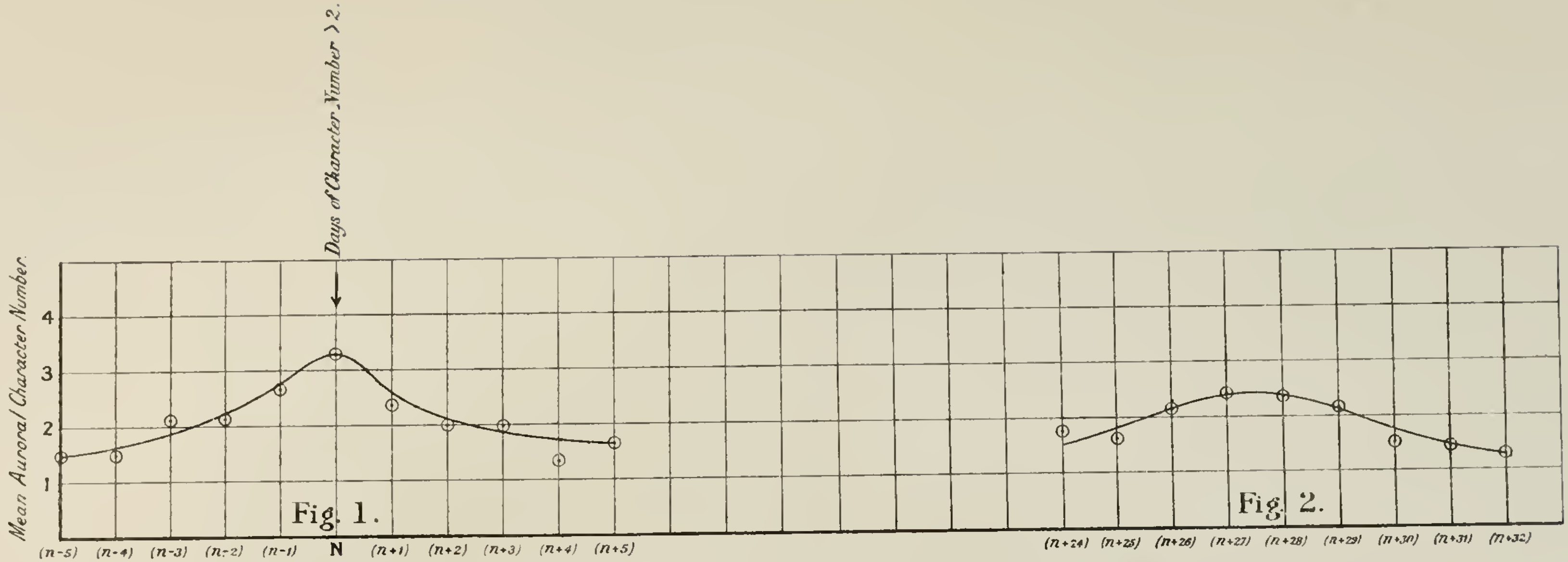
In the paper embodying the results obtained on the "Terra Nova" during the voyage from England to New Zealand, the suggestion was made that observations on the relation between pressure and ionisation in a perfectly screened chamber might throw some light on the origin of the residual ionisation. Observations of this nature have been since made by Downey,* but they do not supply a complete satisfactory answer on this point. Downey made observations at different pressures on the residual ionisation, the metal chamber being placed on a pier running into the Mississippi River, the water being $8\frac{1}{2}$ feet deep underneath the chamber. A linear relation between ionisation and pressure was obtained. This is interpreted by Downey as proof that the residual ionisation is caused by a very hard radiation (the possibility of a spontaneous ionisation or breakdown of the gas being apparently excluded).

There seems little doubt, however, that the "screening" conditions were not very satisfactory. A lower ionisation was obtained in the laboratory than over the water, which suggests a value of not less than 10 pairs of ions formed per c.c. per second over the water at atmospheric pressure. This argues either a significant amount of radioactive substance in the metal, in the enclosed air, in the river waters, or on the pier†. Downey also states that the departure from linearity of this curve is no more than 1·3 per cent. of the highest value, though the individual curves given are not identical and the variations noted from hour to hour in the laboratory were considerable, arguing significant changes in the amount of radioactive material lying on the ground and deposited on the walls of the laboratory building. In these circumstances, it is obviously unsafe to make too wide a generalisation.

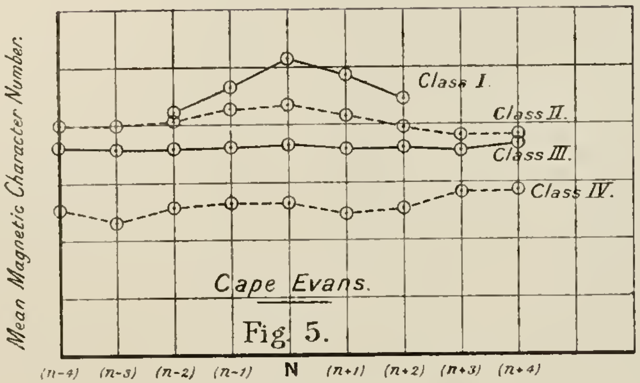
It should not be forgotten that the lowest values are obtained after filtered fresh air is blown into the chamber, and that the value rises steadily and slowly to a maximum for a few days after this treatment. It is therefore difficult to escape the conclusion that radioactive products in significant amounts are suspended in the air within or on the surface of the cylinder some days after the introduction of fresh air, and this seems a clear indication that the zinc cylinder with which our observations were made contained a radioactive substance, notwithstanding the low ionisation values observed. This radioactive substance may well be the cause of the residual ionisation, since the increase to an equilibrium value with lapse of time is quite comparable in value with the minimum value observed by us for the residual ionisation.

* 'Phys. Rev.,' November, 1920.

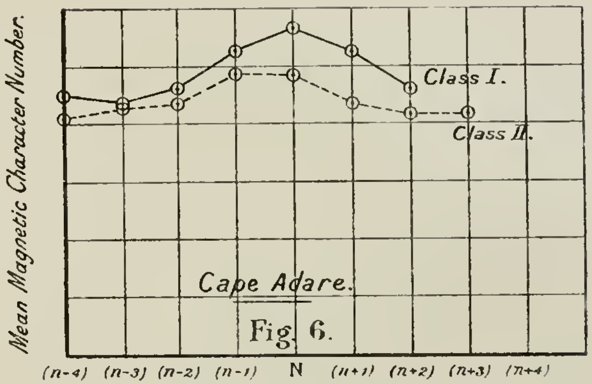
† The "Terra Nova" contributed about two pairs of ions to the total ionisation when lying in Lyttelton Harbour.



Days preceding and following days of Auroral Character Number) 2.



Hours preceding and following hours (N) of Auroral display.



Hours preceding and following hours (N) of Auroral display.

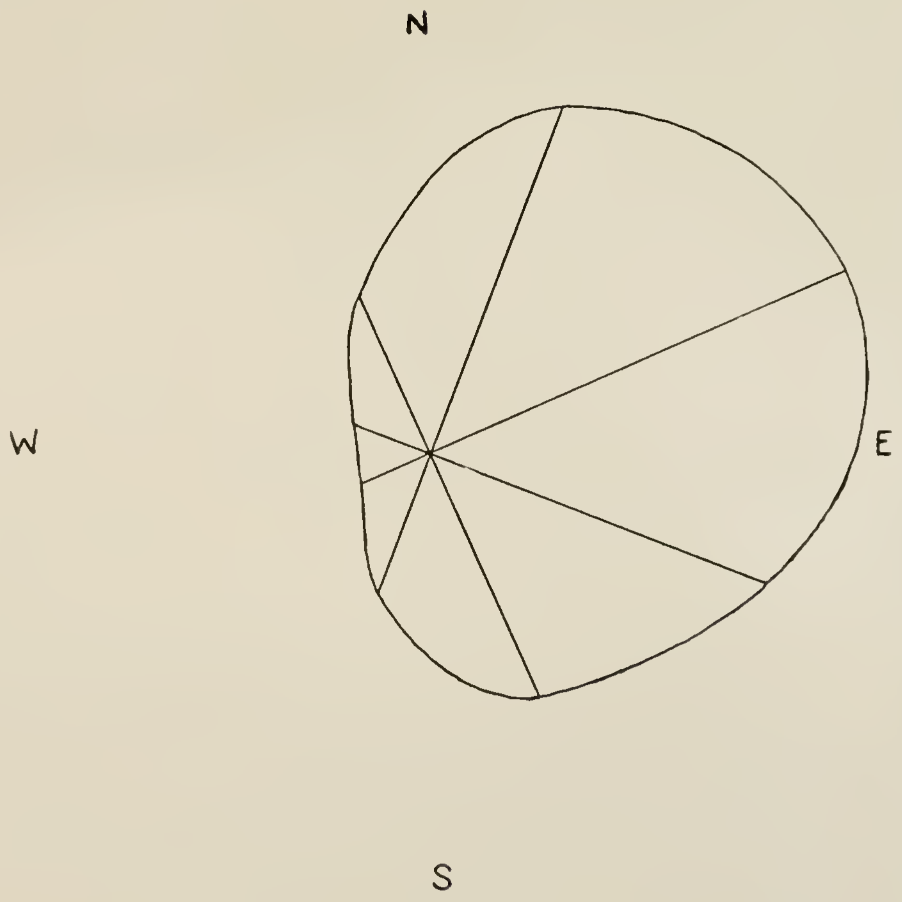


Fig. 3.—Polar Diagram showing Distribution of Aurora in Azimuth—Cape Evans.

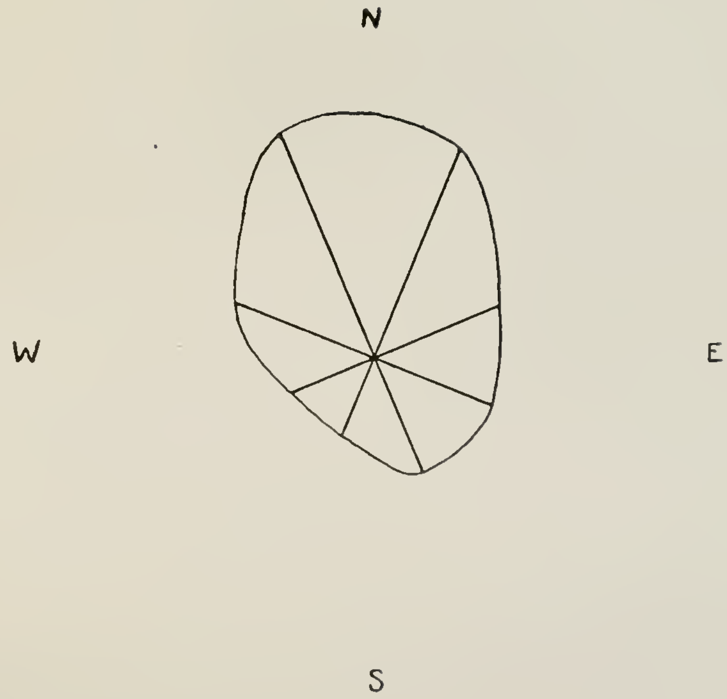


Fig. 4.—Polar Diagram showing Distribution of Aurora in Azimuth—Cape Adare.