TABLE 2.—*Observations of halos of abnormal radii.*

| Observer and date. | Halo of— van Buijsen. | Rankin. | Burney. |
|---|---|---|---|
| | ° | ° | ° |
| Hissink, 1899 | 7.5 | 17.5 | 19.5 |
| Hissink, 1899 | 9.0 | ........ | 19.0 |
| Hissink, 1905 | ........ | 18.0 | 19.5 |
| Besson and Dutheil, 1911 | 9.0 | [1] 18.5 | ........ |
| Andrus and Riley, 1915 | 8.5 | 17.5 | 18.5 |
| Brush, 1919 | 7.0 | 17.0 | 19.0 |
| Grundmann, 1922 | 9.0 | 17.0 | 19.0 |
| Mean | 8.3 | 17.4 | 19.0 |
| Theoretical value with inclination 25° 14.4′ | 8.0 | 17.4 | 18.9 |
| Theoretical value with inclination 24° 51′ | 7.9 | 17.1 | 19.0 |

[1] This halo could be classed almost as well as the halo of Burney.

The values of the radii deduced from an inclination of 24° 51′ clearly show a larger departure from the observed value. Further, for the halos of van Buijsen and Rankin, the radius varies very rapidly with inclination, the sign of the departure being precisely that which results from too small a value of the inclination. The experimental results upon which the value of 24° 51′ is based not being more than approximate, I do not see a decisive reason for rejecting the value of 25° 14.4′.

*Halo of Dutheil.*—A halo of 24° was very clearly seen by Dutheil in 1911 of which the radius was measured.[4] One can explain this by refraction either between the base *c* of the crystal and an oblique face at the other end, or between a prismatic and an oblique face. If these crystals are prisms terminated at both ends by nontruncated pyramids, only the second mode of production is possible; but if these crystals are simple or double pyramids, without prismatic section, it is, on the contrary, only the first mode that is possible.

*Halo of Scheiner.*—It does not appear possible to admit with Doctor Humphreys that the halo of Scheiner and the halo of Feuilleé constitute one and the same phenomenon. There are six observations of the halo of Scheiner; three very old ones—those by Scheiner (25° to 28°), Greshow (26°), and Whiston (29°), which I cite from Bravais; and three recent ones—those by Besson (28°), Andrus and Riley (28° to 29°), and Noyer[5] (28°). These observations assign a value of the radius in the neighborhood of 28°.[6]

[4] Annales de l'Observatoire de Montsouris. 12: 236.

When one passes in review the halos which can be produced by crystals whose oblique faces are inclined either by 19° 28′ (inclination which X-rays seem to designate as corresponding to the prismatic form of ice) or by an angle of which the tangent is in simple relation with tan 19° 28.2′, one perceives that a very large number of these halos have a radius little different from 28°.

Calling $x$ the inclination and placing

$$K=\frac{\tan x}{\tan 19° 28.2'},$$

we find that for values of $K$ smaller than unity that there are no halos of the required size produced; but, if $K$ is given the values 1, 2, 3, or 4, one finds not less than seven. These are enumerated in the following table:

TABLE 3.—*Different methods of possible formation of the halo of Scheiner.*

| | $K$ | $x$ | Faces of incidence and emergence. | Radius of halo. |
|---|---|---|---|---|
| | | ° ′ | | ° ′ |
| No. 1 | 1 | 19 28.2 | $p_1, p_3$ | 27 45 |
| No. 2 | 1 | 19 28.2 | $c, p'$ | 27 45 |
| No. 3 | 2 | 35 15.9 | $p_1, p_4$ | 27 45 |
| No. 4 | 3 | 46 41.2 | $m_1, p_3$ | 27 23 |
| No. 5 | 3 | 46 41.2 | $p_1, p'_6$ | 29 18 |
| No. 6 | 4 | 54 44.1 | $p_1, p'_4$ | 27 45 |
| No. 7 | 4 | 54 44.1 | $m_1, p_3$ | 29 32 |

The halo of Scheiner which I have observed was reduced at its highest point. For that reason it can not be attributed very satisfactorily to mode of formation No. 2, but clearly does not prove that this halo is not produced in that manner. In whatever manner, the most probable value of its radius appears to be 27° 45′.

[5] Annales des Services techniques d'Hygiène de la Ville de Paris. 2: 269, 1920.
[6] I do not believe the error can exceed 1°.

## COMMENTS ON HALOS OF UNUSUAL RADII.

By W. J. HUMPHREYS.

[Weather Bureau, Washington, D. C., June 1, 1923.]

Unfortunately Besson's article on the extraordinary halos[1] had not come to my attention when I wrote the paper he refers to above. Nevertheless, the two papers are entirely different in their lines of approach, and essentially supplementary each to the other—certainly in no sense antagonistic.

Besson's method of computing the inclination of the pyramidal faces of the snow crystal to the principal axis from the radii of the unusual halos is logical, but as these radii are known to only a rough approximation any value computed from them must also be correspondingly unreliable. I tried at first the same method and found 25° to be about right, but did not adopt it because, if the generally accepted goniometric measurements of the pyramidal ice crystal are correct, this value is crystallographically impossible.

But Dobrowolski had shown that none of these goniometric values was at all reliable, and so Besson's method of computing the angle from the radii of the halos again seemed both allowable and desirable. Then came the X-ray determinations of the axial ratio, 1.62, of the ice crystal, a ratio that permits the angle in question to be 24° 51′, which value therefore was adopted.

[1] *Comptes Rendus*, 170: 334, 1920.



The computed radii of the unusual halos, that such snow crystals would give, for a point source of yellow light (refractive index, 1.31) and the correspondingly measured radii are listed in the accompanying table:

| Computed. | Measured. |
|---|---|
| ° ′ | ° ′ |
| 7 54 | 8 12 |
| 17 06 | 17 ± |
| 18 58 | 19 [illegible] |
| 23 24 | 23 20 |
| 24 34 | ...... |
| 31 49 | 32 00 |
| 89 28 | ...... |

The measurements are very unsatisfactory, because, so far as I know, two of these halos have never been instrumentally measured at all, and the others but once each, and because it is not certain to what refractive index (color, or portion of the halo) each measurement corresponds.

The values 8° 12′ and 32°00′ were obtained with theodolites; 17° ± and 19° ± with an improvised plane-table device; and 23°20′ by measurements on the image of the halo in a basin of mercury. In this last case the reported value is 23°57′, but this reduces to 23°20′ on applying to it the same correction that must be applied to the simultaneously made measurements on the 22° halo.

In short, then, Besson computes the shape of the ice crystal from the radii of the halos; I take crystallographically possible crystals as determined from highly accurate X-ray measurements, and from among them find one that alone accounts, to well within errors of measurement, for seven, that is all, or, at least, all but one, of the recognized halos of unusual radii.

If that remaining unusual halo, of radius 28°, roughly, does exist, presumably it is formed in the manner suggested by Besson, but then it should be accompanied by a group of other halos, none of which, apparently, has ever been reported.

But whether this particular halo exists or not there is a great number of others that certainly do, and together they afford endless opportunities for observation and numerous interesting problems for the mathematical physicist, lines of work, both of them, in which Besson has long been a master.

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## WINDS AND WEATHER OF CENTRAL GREENLAND: METEOROLOGICAL RESULTS OF THE SWISS GREENLAND EXPEDITION.[1]

By CHARLES F. BROOKS.

[Clark University, Worcester, Mass., May 15, 1923.]

In the summer of 1912, Dr. Alfred de Quervain with three others crossed the south central part of Greenland from Jakobshavn to Angmagsalik, while another party headed by Dr. P. L. Mercanton made meteorological and glaciological observations along the west front of the inland ice near Jakobshavn. During the following winter, Dr. W. Jost and Dr. A. Stolberg made aerological observations at Godhavn, on the south coast of Disco Island. The meteorological results obtained by these three sections of the expedition will be discussed in succession.

### I. SUMMER WEATHER ON THE ICE SHEET.

The ice sheet is a giant cooler projecting southward into the realm of a relatively warm ocean and spreading northward into the paleocrystic ice of the Arctic Ocean. Over such a cooler the air is continually shrinking, and, becoming heavier, it tends to slide off the ice. The prevalence of down-slope winds, even in midsummer, was strikingly in accordance with Hobbs' theory of the glacial anticyclone.[2] Under ordinary conditions, however, this would have been less marked, for there was a preponderance of general gradients westward across southern Greenland during the ascent, and eastward ones during the descent. No observations showed that a low-pressure area ever crossed the inland ice north of de Quervain's route. Some secondaries, however, passed across the southern tip. The cyclones on the west coast went north, just as those of the United States and Europe go east or northeast, and showed the characteristic barrier effect of the cold (NW.) wind in the left front quadrant, to the warm (SE.) wind (off the inland ice) in the right front quadrant. Strange though it may seem, the ice cap supplied the warm element of the cyclone under these conditions, when the air was drawn all the way across Greenland precipitating snow and liberating latent heat on the east slope and warming by compression on descending the west slope.

It was not to be expected that the temperatures over the inland ice would rise more than a degree or two above freezing, except under föhn conditions, when the wind is blowing right across Greenland. Nor was it thought that temperatures would fall much below freezing except over the surface where there was no wet snow or standing water to supply latent heat of fusion while the sun was lowest in the sky. Thus, it is not surprising to learn that the average temperature was 30.7° F. during the first 13 days the party was on the ice in the zone where melting was in progress, and that the departures of individual days amounted to only 2° to 4° F. notwithstanding a range of altitude from 550 to 1,900 meters above sea level. "On July 3 at 1,936 m., we suddenly entered a cold region," says de Quervain, to cross which required 13 days, as it extended 280 kilometers over the divide and down to an altitude of 2,250 m. on the east slope. The mean temperature of this zone was 14° F., and the means of the individual days were generally not more than 3° from this. The highest temperature was 25° and the lowest temperature, −7° F. For the last 5 days of the journey, in the eastern zone of melting, the mean was −0.02° C. (31.96° F.).

Since the sun remained above the horizon continuously during most of the crossing, the highest and lowest temperatures occurred just 12 hours apart, between 2 and 2½ hours after noon and midnight, respectively. The temperature of June 23–24 is described as characteristic of that of the border zone. The minimum, 23° F., came after 1:30 a. m. (the sun did not set) and the maximum, 35° F., between 2 and 3 p. m. Direct solar heating and perhaps also compression of descending air served to raise the air temperature above that of the ice. In the central zone, it seems likely that temperatures fall to −25° C. (−13° F.) in midsummer, and that the maximum daily range is 25° or 30° F. On cloudy days the mean range was 6.1°, on partly cloudy 9.5°, and on clear days 14.9° F. As the range in temperature is restricted where thawing and freezing alternate, it must be less in summer than at other seasons. Thus, in August and September, Nansen found daily ranges of temperature appreciably larger than those encountered by de Quervain. With continuous darkness in winter the range must be less than in autumn or spring. The rapidity with which the summer temperatures must plunge into the unknown cold of winter is shown by the contrast between the mean of all de Quervain's observations on the crossing, 23.9° F. (June–July), and Nansen's corresponding figure, 11.7° F. (August–September).

### TEMPERATURES AND WINDS.

On the cold, sloping surface of the inland ice, which is smoother even than the waved surface of the ocean, it is not surprising that the air was usually smoothly flowing down the slope. Only at 6 of the 200 observations were there calms. At times the wind blew so hard that a man on skis, with two poles to push with, could not make

[1] Alfred de Quervain, P. L. Mercanton, and others: Ergebnisse der Schweizerischen Grönland expedition, 1912–1913. *Denkschr. der Schweizerischen Naturforschenden Gesellschaft.* Bd. 53. Zurich, 1920, 402 pp., maps, diagr.

[2] W. H. Hobbs: The rôle of the glacial anticyclone in the air circulation of the globe. *Proc. of the Am. Phil. Soc.*, Aug., 1915, 44: 185–225, 11 figs. Reviewed in *Bull. Am. Geog. Soc.*, Dec., 1915, 47: 963.