

This report by Mr. Bliss was of interest in confirming the presence and the length of the inferior segment of the 46° -halo also reported by Prof. Hastings in his article following. Other reports on these halos may reveal further interesting features, but it is particularly to be regretted that Mr. Bliss did not measure or photograph his phenomenon, for, as pointed out below, it is probable that the supposed 22° -halo was really the circumscribed halo of 22° sometimes called the Oval of Venturi (see this REVIEW, July, 1914, 42:439 and fig. 10). Our observations still emphasize the great need in this country for more accurate observations and measurements of halos. Mr. Andrus's observations (p. 214) deserve special commendation on this account. Other observations of the halo of May 20 reveal the fact that the anthelion and the oblique arcs of the anthelion were certainly observable at Reading, Pa., and at Atlantic City, N. J.; but as pointed out elsewhere (MONTHLY WEATHER REVIEW, July, 1914, pp. 434-435) the mere observation is of relatively small value, and our reports from those stations do not tell us the angle between the arcs of the anthelion nor their precise angular length.—C. A., jr.

HALO OF MAY 20, 1915, AT NEW HAVEN, CONN.

By Prof. C. S. HASTINGS.

[Dated: Sloane Laboratory, Yale University, May 21, 1915.]

A remarkably vivid solar halo was observed at New Haven, as at many places in the eastern portion of our country, on May 20, 1915. There were some features of peculiar interest which may have been overlooked and which are important as bearing upon the theoretical explanations of phenomena, often of extraordinary complexity, and always of great popular interest. With a view of interesting meteorologists in a theory which has been quite completely worked out and published¹ many years ago, I venture to send you an account of observations made by myself and companions together with certain theoretical conclusions. All significant observations were made between 11:30 a.m. and noon, while the sun was at an altitude of 68° or more.

The most surprising features of the halo at first glance were the extreme liveliness of the colors and the impressive darkness of the space inside the apparent circle, a contrast far surpassing any previous cases observed by us. The ring appeared notably more brilliant above and below than east and west of the sun. A careful search for appendages to the ring was without fruit until my attention was directed to an arc—perhaps 60° in extent—vertically below the sun and bisected by the vertical circle through the sun. This was relatively faint, but of purer colors than those of the smaller ring. There could be no doubt that this was a portion of the well-known 46° -halo and was attributable to refraction by means of crystal faces at right angles to each other, such as are found at the bases of hexagonal ice crystals.

It will be observed that the whole phenomenon was no more surprising for its brightness than for its simplicity, and it is just this latter feature which renders it particularly important from the standpoint of the theorist.

The feature which first impressed itself upon the mind of the writer as an indication that we did not have here the familiar 22° -circle was the relative darkness of the sky within the ring. It was inconceivable that fortuitously arranged crystals of ice could yield so intensely colored a circle with so little diffused light that the sky

within its area was a blue sky, far indeed from being milky, which it became a few minutes later. If not explicable by fortuitously arranged crystals it was not the 22° -circle at all, but the "Oval of Venturi," which the upper and lower tangent arcs of the 22° -halo form by uniting when the altitude of the sun is sufficiently great. If this were the true type the horizontal diameter of the ring should be slightly greater than the vertical and the upper and lower portions of the ring should be brighter than the eastern and western portions. The first condition I thought I established by rough measurements immediately after the question as to the nature of the phenomenon entered my mind, while the second condition was manifest to any observer whose attention was directed to it.

Very fortunately there is independent and perfect evidence for the correctness of my conclusions. Mr. Charles N. York, of this city [New Haven, Conn.], had the happy thought of photographing the ring and secured an excellent negative on an 8 by 10 plate.² (See fig. 1, opposite.) This shows perfectly that the ring had a horizontal diameter about 7 or 8 per cent greater than the vertical, and that the upper and lower portions were much brighter than the lateral portions, the distribution of light being symmetrical with respect to a vertical circle through the sun. Naturally, the angular extent of field was far too small to show the fragment of the 46° -circle; as a matter of fact the angular value of the plate was only just adequate for taking the whole of the ring. Exactly what instant the exposure was made is unknown to me,³ but it was after the first moments when my companions and I observed it wholly without cirrus clouds within the ring.

To summarize the observations we may say that this halo was a magnificently developed one of extreme simplicity, having only two elements, namely, the Oval of Venturi and a fragment of the 46° -circle. The theoretical explanation is also simple. We conclude that only a single kind of ice crystals was present, namely, elongated hexagonal prisms with bases at right angles to their axes: that these prisms were falling with their axes horizontal and, in general, rotating about their axes. The ring, or oval, was produced by refraction through two alternate faces of the prism whenever a crystal at about 22° from the sun happened to present itself in a favorable position—that is, whenever the light thus refracted should be deviated by an angle little different from the minimum of 22° .

The fragment of the 46° -circle was due to those crystals which happened to be at this angular distance from the sun and so placed that light from the sun could enter at a basal face—vertical in position—and emerge at a prismatic face which happened to be in such a position that the deviation should be very near the minimum of 46° . The high degree of saturation of the colors is due to the obviously narrow range of possible departure from this minimum. A simple calculation, or geometric construction, shows that for minimum deviation in a 90° angle of ice the light should enter one face at an angle of 22° from it (an "angle of incidence" of 68°) and emerge at the other at the same angle; but this is just the angle at which sunlight would fall on vertical surfaces at the time of the observations, the zenith distance of the sun being very nearly 22° during the whole. Here we have a case

²The accompanying beautiful large-scale photograph of the solar halo of May 20, 1915, we owe to the enthusiasm and generosity of Charles N. York, of New Haven, Conn. For the benefit of those who may wish to attempt halo-photography in the open, Mr. York sends the following information:

³The photograph reproduced here, was made at 11:45 a. m. (75th mer. time), using a Goetz "Dagor" lens of 9½ inches focal length, and stop 32. The plate was an 8 × 10 Stanley "Commercial", exposed behind a "15-time" ray filter for $\frac{1}{10}$ second. A "pyro" developer was used.

¹Hastings, C. S. Light. Chas. Scribner's Sons, New York, 1901.

in which the existing portion of the 46° -circle was in fact produced by oriented crystals and so far supports the view advocated on page 219 of the work cited above, namely, that this circle is always produced in a similar way and that the accepted explanation by Cavendish, which attributes it to the action of fortuitously directed ice crystals, is quite inadequate. Among my notes of past observations I find those describing a halo seen at this place on February 13, 1914, when a portion of this halo of very unusual distinctness was seen above the sun, whose altitude was $22^\circ 7'$. Here we had a case where the refracted light entered a horizontal lateral face of the ice crystal and emerged at a vertical base, with equivalent angles of incidence and emergence.

On May 20, 1915, a certain feature was missing which might be expected in a halo produced by oriented crystals, namely, the parhelic circle—that is, the colorless horizontal circle passing through the sun. This feature is said to be very frequently observed in northern

Europe, but, at least as far as the present writer's observations are decisive, is not often seen in this region. In the general theory referred to above, it is argued that, contrary to the accepted views, this circle can only be due to total reflections from the interior of prisms with continuously vertical faces. In the case under discussion we had, at first view, all the necessary conditions, yet not a trace of the parhelic circle could be found. The theoretical difficulty here presented vanishes when subjected to quantitative test. Owing to the great altitude of the sun the projected area of the total reflecting faces was reduced to less than three-tenths their true area even in their most favorable position at an azimuth 180° from the sun; in general it would be much less than this. This is in complete accordance with the fact that I find no record of a parhelic circle with the altitude of the sun within 10 degrees as great as that observed. It would be difficult to account for this limitation as regards altitude unless the total reflection explanation be accepted.