The copy filmed here has been reproduced thanks to the generosity of:

Archives of Ontario
Toronto

The images appearing here are the best quality possible considering the condition and legibility of the original copy and in keeping with the filming contract specifications.

Original copies in printed paper covers are filmed beginning with the front cover and ending on the last page with a printed or illustrated impression, or the back cover when appropriate. All other original copies are filmed beginning on the first page with a printed or illustrated impression, and ending on the last page with a printed or illustrated impression.

The last recorded frame on each microfiche shall contain the symbol → (meaning "CONTINUED"), or the symbol ▽ (meaning "END"), whichever applies.

Maps, plates, charts, etc., may be filmed at different reduction ratios. Those too large to be entirely included in one exposure are filmed beginning in the upper left hand corner, left to right and top to bottom, as many frames as required. The following diagrams illustrate the method:

L'exemplaire filmé fut reproduit grâce à la générosité de:

Archives publiques de l'Ontario
Toronto

Les images suivantes ont été reproduites avec le plus grand soin, compte tenu de la condition et de la netteté de l'exemplaire filmé, et en conformité avec les conditions du contrat de filmage.

Les exemplaires originaux dont la couverture en papier est imprimée sont filmés en commençant par le premier plat et en terminant soit par la dernière page qui comporte une empreinte d'impression ou d'illustration, soit par le second plat, selon le cas. Tous les autres exemplaires originaux sont filmés en commençant par la première page qui comporte une empreinte d'impression ou d'illustration et en terminant par la dernière page qui comporte une telle empreinte.

Un des symboles suivants apparaîtra sur la dernière image de chaque microfiche, selon le cas: le symbole → signifie "A SUIVRE", le symbole ▽ signifie "FIN".

Les cartes, planches, tableaux, etc., peuvent être filmés à des taux de réduction différents. Lorsque le document est trop grand pour être reproduit en un seul cliché, il est filmé à partir de l'angle supérieur gauche, de gauche à droite, et de haut en bas, en prenant le nombre d'images nécessaire. Les diagrammes suivants illustrent la méthode.

1	2	3

1
2
3

1	2	3
4	5	6

REPRINTED FROM THE JOURNAL OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA, NOVEMBER, 1918

1918

94

SOME SPECIAL FORMS OF HALOS

BY

A. F. HUNTER

TORONTO:
1918

SOME SPECIAL FORMS OF HALOS*.

By A. F. Hunter.

WHAT I propose to do is to make a selection from my notes of past years on some of the rarer examples I have seen of the optical phenomena of the atmosphere, and to explain each example that I select. It has not been my practice to note every halo I saw; that would be useful only in an observatory for a complete census of them. I noted only rare and interesting forms, and this paper will be a selection from that selection, giving some of the rarest forms.

The halo, as usually figured in the textbook, has a composite nature, consisting of six or seven parts, and is really a group of several halos formed in ways different from each other.

Halos are produced by thin sheets of snow crystals in the higher parts of the air. A familiar picture of snow crystals shows:—

1. The constant angle which the crystals always have, viz., 60°. No difference whether the crystal be large or small, it

*The introductory part of a paper on "Halos," read at the Meeting of the Society in Toronto, November 6, 1917, the remaining portion, viz., on "Distorted Solar Halos," having been published in this JOURNAL for January, 1918.

angles are always the same (60°). This is the chief peculiarity of the hexagonal system of crystallization, and there are other substances, such as calc spar, which crystallize in this system, besides common ice and snow. The picture also shows:—

2. When broken into pieces, the minute fragments have smooth faces, from which reflexions can take place, and the pieces also have axes of unequal length; in other words, the fragments are very small prisms of ice.

These small prisms, spread thinly in wide sheets in the higher air, as they often are, make halos of reflexion, and also halos of refraction, which sometimes all appear together in the combined form shown in the ordinary textbook figures, but the parts of which have really nothing whatever to do with each other, being formed in the two different ways. The halos of refraction result from the combination of rays of light refracted to the same extent through the small prisms with the same angle (60°), all refracting the same amount whatever their sizes may be. And the halos of reflexion result from the combination of small images of the sun or moon all reflected off the faces of the small prisms. Our work in this paper will chiefly amount to an analysis of the combination halo into its different parts.

When the light of the sun or the moon is refracted through fog, i.e., through small particles of water, instead of through snow particles, the optical effect is entirely different from what we see through the snow crystals. Through fog the sun's light or the moon's light makes what is known as the corona, which is likewise a spectrum, circular, but much wider, and also closer to the orb than the one that results from snow crystals. One often sees a corona around an electric street light at night, especially in damp weather.

In the higher parts of the air there can be only the finest snow dust, the larger snowflakes being confined to the lower air. We see this fine snow dust in the cores of hailstones when broken open by a hammer, and in the fine snow drifted into wooden buildings through small crevices that will not admit the larger snowflakes; and also in the blizzards that occur in the dry climate of the Canadian northwest provinces, and on the highest parts of lofty mountains.

The cause of the production of halos by means of snow crystals was known as long ago as the time of Newton, who wrote on this subject, and it was perhaps known for a longer time. The one who gave the most stimulus to the subject in modern times was Auguste Bravais, a French scientist, who wrote about two-thirds of a century ago. It was Bravais, for example, who first pointed out that "mock suns" are due to refraction through crystals all having their longer axes vertical (a view that has been generally adopted by scientists), and he enunciated several other fundamental principles in the theory of halos, now generally accepted.

As an example of how the formation of the halo takes place, we may select the case of the ordinary sun circle at 22°. A snow crystal near the line from the sun to the observer sends out a spectrum of its own size, another sends out another spectrum, and so on, until the entire circle is built up. The eye of the observer, looking at the snow crystals in the minimum position, catches only those spectra that pass in his direction, although all other snow crystals in the air having the proper position are refracting each a spectrum in some direction at the same time.

The snowline in this latitude in midsummer is 9,000 or 10,000 feet, about two miles or three kilometres, so that in the very hottest weather of summer we are never more than two miles distant from snow at any time.

It is important to realize rightly in what stratum of the air halos usually occur; they are in the region above the clouds, as a rule, viz., in what has been called the "stratosphere," doubtless because of the diffuse condition of its cloud matter. This stratum is the cirrus haze above all the forms of definite clouds that we know. The haze occurs in the lower parts of the stratosphere, and probably also extends far up into it, at certain times.

The thinness of the haze-film or sheet determines the visibility of the halo. If the haze is too thick, there is no optical effect. The play of colors in the soap bubble and in thin crystals occurs only when they have a thinness commensurate with the light waves, and a similar state of things exists with the halo conditions. In summer time when the snowline is high, say two miles high, the snow-crystal-film of the higher air is thinner than in winter time, and the circular halo then often has the rainbow colors; but in winter this is rare because the snow film is usually too thick to give the pure spectrum colors, there being then too much overlapping of the colors, with the result of making white halos, or nearly so. When there is a moderate amount of overlapping of colors, only the edges of the halos show color.

The cirrus haze of the stratosphere is subject to the action of electro-magnetic forces, and the repulsion of similarly electrified particles of snow amongst themselves may also account for the very diffuse condition of the cirrus haze and for the cloud-wisps, which also produce halos.

Electro-magnetic forces are especially present in "mock suns," and in sun pillars and other halos of reflexion. Some electrification of the particles of snow dust must occur.

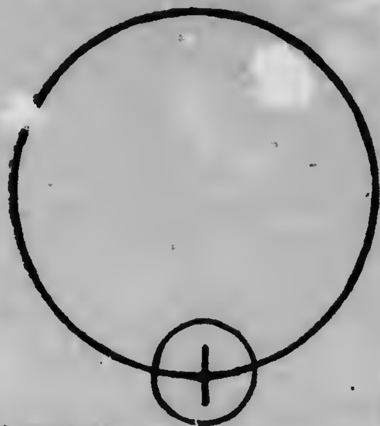
I have seen the statement in print that the halos are linked with the sunspot phenomena. Dr. Besson, in an article on halos in the U.S. Monthly Weather Review (Washington) for July, 1914, p. 437, alludes to this connection in the following words:— "The annual number of days with halo seems to show a variation that is either parallel with or inversely as the variation in sunspots." It is also obvious that they are numerous when auroras are numerous.

Finally, a halo is often in the forepart of a cyclone, and thus serves as a warning or signal of the coming storm. For many ages this has been cherished in weather lore as a sign of a future storm, and it is often a good sign, but not always so.

The foregoing general remarks on halos may help us to understand the particular cases we will now take up, in their order of time, most of which were observed by the writer at Barrie, Ont.

Great White Horizontal Circles. On March 3rd, 1890, at 7.30 p.m., there was an unusual halo of the moon at Barrie. A great white circle passed through the moon's disk and extended horizontally around the sky. This circle, of the same breadth and altitude as the moon, was exceedingly well-defined, being complete around the entire sky, and the centre of it was the zenith. The ordinary first circle was faintly visible at the same time, and also an upright or vertical shaft of light was faintly visible, having the same diameter as the moon's disk and passing through it. There were three features of the great circle of this halo that I noted particularly, viz.:—

1. It was perfectly horizontal.
2. It was white, or rather the color of the moon itself.
3. While so extensive, and the band of light as wide as the moon, it was uniformly bright around the entire sky.



HALO OF THE MOON OBSERVED AT BARRIE, ONT., MARCH 3, 1890
The large horizontal circle had the zenith for its centre.

The air had a foggy appearance, and there was a slight fall of fine snow at the time, but not thick enough to obscure the moon or the halo. White circles like this must arise from exterior reflexions from the flat faces of the crystals, as there would be spectrum colors, at least on the edges, if there was any refraction of the light through them. We may regard the small snow crystals as small mirrors or looking glasses all hanging in one position in the air, or rather, gently falling through it. The reflexions of the image of the moon off their faces all combined together gave the halo, which, speaking literally and truthfully, was an enormous halo around the observer's own head, and like the similar case of the rainbow where everyone sees his own rainbow, each observer, in a strangely human way, would see this vast evidence of his own canonization and not the other person's.

The white cross-bars through the moon, made by such external surface reflexion, was a common form of halo the same winter, the snow particles forming it always appearing to be in the lower air; whether they actually were or not, I cannot say.

"Mock-suns," made by refraction through crystals in the vertical position, as Bravais pointed out, and "sun-pillars," i.e., the upright white solar shafts of light made by reflexions of the sun's image off the surfaces of crystals that are in the horizontal position, visible after as well as before sunrise or sunset, were also both common forms during the same winter of 1890.

Some years later, when reading the Narrative of the polar expedition of Capt. (afterward Sir) Francis Leopold M'Clintock, who solved the fate of Sir John Franklin in the Arctic regions, and who received the reward offered for the desired information, I found a description of a halo similar to the one I am describing, and I can commend his account of it for brevity and for pointed description, to anyone seeking to increase our knowledge of these phenomena.

From "In the Arctic Seas," by Capt. M'Clintock, R.N., p. 68:

"One of those strange lunar phenomena which are but seldom seen even here (Baffin Bay, N. Lat. 74½ deg., Long. 70 deg. W., i.e., off the N. end of Baffin Land), a complete *halo encircling the moon*, through which passed *a horizontal band of pale light that encompassed the heavens;* above the moon appeared the segments of two other halos, and there were also mock moons or paraselenæ to the number of six. The *misty atmosphere* lent a very ghastly hue to this singular display, which lasted for rather more than an hour."

In the halo I observed on March 3, 1890, I noted especially those features I have italicized in Capt. M'Clintock's description.

Solar Parhelic Circles. On April 25th, 1898, at 6.30 p.m., I observed a halo of the sun having a partial horizontal circle. The white band through the orb was well defined for some distance on both sides of the sun. At the same time the first and the second circles were both well defined, and the "mock-suns" and the upper arc, tangent to the first circle, were also bright, but those of the second circle were not noticeable.

On March 5th, 1902, I observed another great circle through the sun; which I saw at 11 a.m. and at 11.15 a.m., but it was not visible at 12 noon. The first and the second circles of the halo had been visible as early as 9.30 a.m., but the second circle was not very distinct by 11 o'clock when the great circle became visible. The "mock-suns" at the first circle were not strong; but on the great circle, which was white, knots were visible at intervals, not more than four altogether, though perhaps five if we count the "anti-sun." The two primary "mock-suns" would make seven. This example of the parhelic circle appears from my notes made at the time of its appearance to have been complete, but it did not impress me so much by its brightness as that of the moon twelve years before.

Again, on April 7, 1917, the well developed halo of the moon that attracted so much attention over a portion of Ontario had a partial circle of this kind at the writer's place of observation (Barrie), but the horizontal band did not extend far beyond the second circle.

Thus, of four horizontal circles seen in 28 years, viz., two of the sun and two of the moon, only two were complete. This shows that instances of the kind are not very common, although other observers may have noted more during the same period.

Colored Arcs in the Zenith. It was while observing a halo of the sun on May 14, 1898, that I first saw a close connection between two "mock-suns" and the colored arc in the zenith, or as it is usually called,—the upper tangent arc to the second circle,—though it does not appear to have any connection with that circle.

and occurs simultaneously with it only on some rare occasions. At 5.50 p.m. both "mock-suns" and arc were visible. The brilliancy of the arc varied from minute to minute, and it lasted altogether for 15 minutes. When one "mock-sun" flared bright, the opposite arm of the arc became also bright, and *vice versa.* Having observed on that occasion the close alliance between these two parts of halos, it then became my practice to look for an arc when "mock-suns" appear, and in this way I have more frequently observed them than I could otherwise have done, though they do not always appear together. During the twenty years that have elapsed I have observed altogether about a dozen arcs, some bright, others feeble. One which I saw at 8.50 a.m. on March 3, 1917, was intensely bright, and in addition to the arc there were at times faint cross-bars, of which the sun was at the intersection. The frosty air at the time was foggy or hazy. Within the concavity of the arc was a fluorescence of the ultra-violet rays.

Sun Pillars. On Feb. 17, 1899, I observed a perpendicular shaft of light or sun pillar rising from the sun, which was shining dimly through a thick stratum of haze. The parts of the pillar fluctuated in brightness like the streamers of an aurora, and at about the same rate. It appeared to be evident from this fluctuating example of halo that there is a resemblance between halos and auroras in their formation. The drift of the streamers in the aurora are probably due to motion of the snow dust in the very highest part of the atmosphere, the same substance that visualizes halos. This halo in 1899 first brought to my attention the probable intimate connection between halos and the electro-magnetic forces in the higher parts of the atmosphere, and since then I have been able to pursue the subject with more advantage.

The altitude of at least some sun pillars would seem to be very great, as one indicated that I saw on March 7, 1912, at 6.50 a.m., just before sunrise. A shaft of strong light rose from the horizon, showing where the sun might be expected to rise, and in addition to being intense, it was crimson-colored, having the same tint as the clouds have at that time when the sun's rays are diffracted. The sun itself appeared above the horizon about twenty minutes later. I can imagine a primitive people, seeing a flaming sword like this rising out of the horizon, would think that the last day had come. In fact, many myths have had their origin in such appearances, and nature myths have now come to be studied with more profit than formerly. An interesting paper on this subject alone could be written.

Conclusions. It may have already become evident to those who have followed closely the explanations of the different forms of halos thus far, that there are two positions in which the longer axes of the snow crystals commonly lie. We have found:—

1. Some with the prisms vertical.
2. Others with the prisms horizontal.

These two directions may even exist simultaneously, and it is in this way the cross-bars are formed in halos of reflexion, and the "mock-suns" and tangents in halos of refraction. It will be recalled that auroras adopt the same two directions, viz., the vertical streamers and the horizontal bands. We thus find a close parallel between the two classes of phenomena,—auroras and halos. The halos show us the electro-magnetic condition of the higher parts of the air at times when the light of the sun or the moon makes it impossible to see any aurora if it should be present. In other words, we are getting the same information, whether the sun or the moon is shining, or whether it is absent, and the two periods are the complements of each other and make the record almost continuous if we could always see the clear sky.*

* On the view that auroras and halos are indexes of atmospheric electrification, there should be a maximum of the solar halos between 9 and 10 a.m., corresponding with the maximum of the auroras about 9 or 10 p.m., the two coming simultaneously with the two maxima of daily electrification of the atmosphere occurring about those times of the day (12 hours apart) which latter so many investigators have shown. The solar halos I have noted, during a period of thirty years, have the ratio of 4 forenoon, to 3 afternoon, halos; but as I recorded only rarer forms, and did not make a complete census, the proof of a maximum of halos in the forenoon would not necessarily lie in this data. The trend, however, toward a forenoon maximum, is evident from the casual record I have made of the rarer forms, and in accordance with the maxima of atmospheric electrification.

Apart from the work of the sounding balloons, the loftiest parts of the atmosphere can be studied only by means of halos. auroras, sunset glows, and other phenomena of the cirrus hazes sometimes seen in those higher altitudes. The optical phenomena which are common enough, especially in our Canadian winters, promise an abundant return of data if properly worked. But this can only be done when the ordinary optical phenomena of the atmosphere are fully understood and interpreted by as large a number of observers as possible. A person who can discriminate what is evidence from what is not, is capable of making an observation that may serve to help this line of science,—the optical phenomena of the air. Speculation is always of secondary value; it is only a good observation that has value of the highest kind.