Similar phenomena, including some unusual forms, were observed on the same day at other places in the north central portion of the United States. At Lake Okojobi, near Milford, Iowa, for example, there were seen at about 3:30 p. m., among other forms, the oblique arcs of the anthelion, the anthelion of 180°, circumzenithal arc, 22° and 46° halos, circumscribed arcs of the 22° halo, and apparently parhelia of 90°. The circumzenithal arc, visible here, could not be seen at Ellendale owing to the higher elevation of the sun at the time at which that observation was made.— *W. R. Gregg.*

THE BOULDER HALO OF JANUARY 10, 1918.

By EDGAR W. WOOLARD.

A brilliant halo display occurred at Boulder, Colo., on January 10, 1918, some portions of the complex remaining visible throughout the major portion of the day.[1] The writer, through his general interest in natural phenomena, was led to make a sketch about 10 a. m., one hundred and fifth meridian time, when the sun's elevation, as afterwards computed, was 19° 50′.

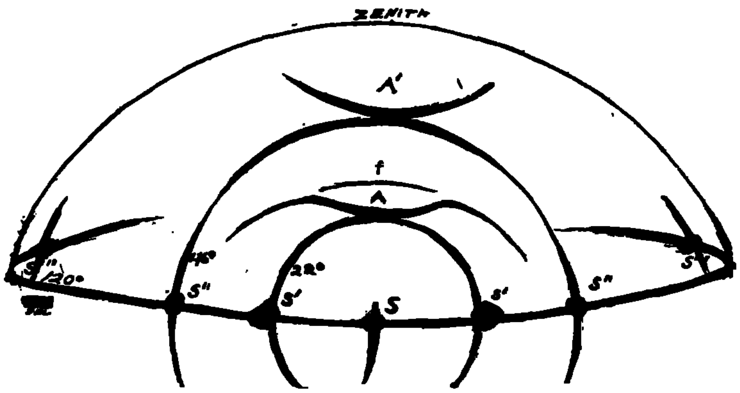

FIG. 1.—Original sketch of the Boulder (Colo.) halo of Jan. 10, 1918, at about maximum development, 10 a. m., one hundred and fifth meridian time.—*E. W. Woolard.*

At that time, the writer was entirely unacquainted with the appearance, nomenclature, and theory of halos, so that the sketch, figure 1, made in pencil on the spot and afterwards inked over, is a perfectly faithful and unprejudiced record of what was actually plainly visible; additional phenomena, not seen because not looked for, probably were present also. It has since developed that this drawing records some unusual features which justify placing it on record.

The most noteworthy features are: The curvature of the sun-pillar, obviously due, as pointed out by Dr. W. J. Humphreys, to a prevailing tilt (eastern edge up) of the reflecting faces, caused, presumably, by gentle surface winds incident to the onset of a cold wave the night before—the atmosphere down to the surface of the earth, was filled with falling ice crystals;—the paranthelic arcs; and the arc *f* between the halos of 22° and 46° and symmetrical about the vertical circle through the sun. This latter arc, previously reported by Parry and by Ferguson, is produced, as Hastings explains,[2] by refraction through randomly oriented ice needles in their most stable position, viz, with a pair of the side faces horizontal.

Figure 2 gives a representation, on the customary conventional "projection," of the halo computed from theory in the usual manner; it will be seen that it is in substantial agreement with observation. It may be helpful to indicate here the method employed to locate

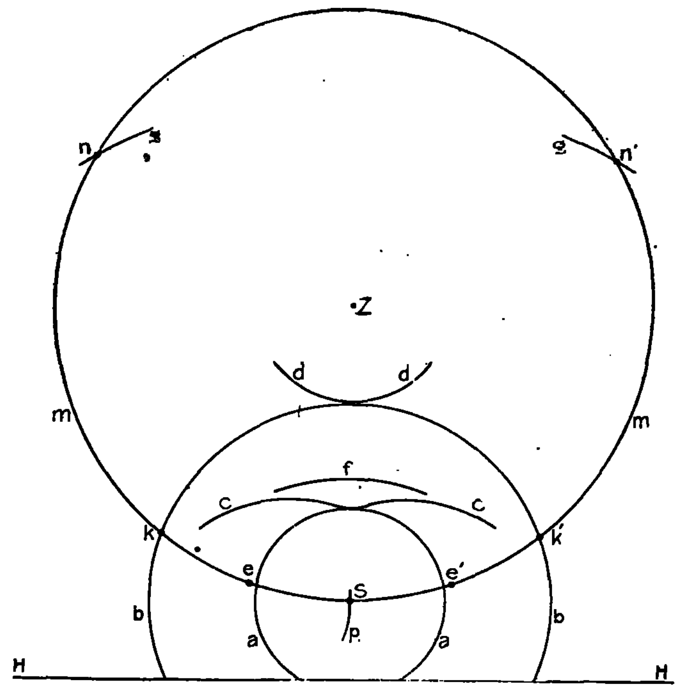

FIG. 2.—The Boulder (Colo.) halo of Jan. 10, 1918.—*HH*, horizon; *S*, sun; *p*, sun-pillar curved owing, probably, to prevailing tip of crystals caused by gentle surface winds *aa*, halo of 22°; *e*, *e′*, parhelia of 22°; *CC*, upper tangent arc of halo of 22°; *f*, "Parry's upper arc"; *bb*, halo of 46°; *k*, *k′*, parhelia of 46°; *dd*, circumzenithal arc; *Z*, zenith; *mm*, parhelic circle; *n*, *n′*, paranthelia; *gg*, portions of paranthelic arc. Elevation of sun, 19° 50′; temperature, —4° F.; air very quiet, and filled with falling ice crystals.

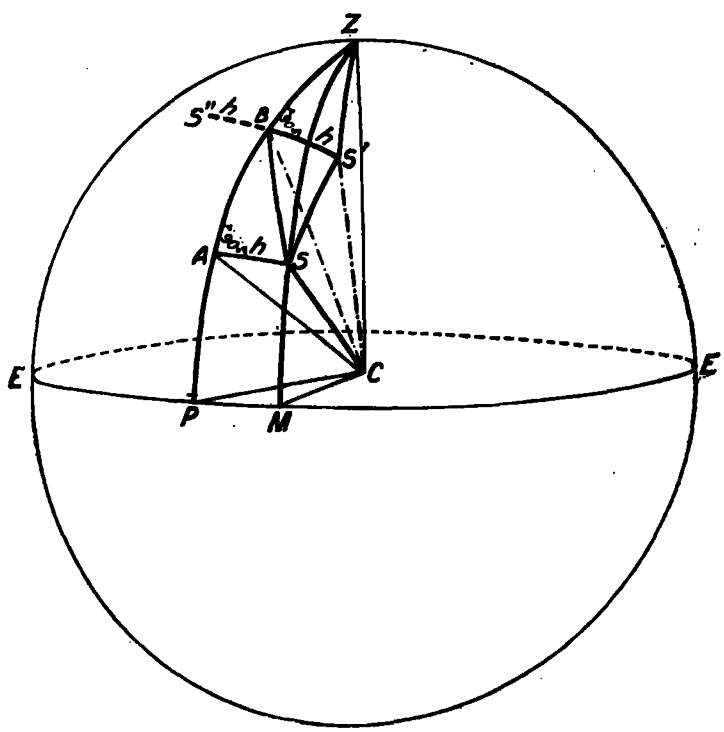

FIG. 3.—*EZE*, celestial hemisphere; *EE*, rational horizon; *C*, observer, and crystal; *S*, sun; *SC*, incident ray; *AC*, projection of incident ray on principal plane of crystal; *ZAPC*, extension of principal plane of crystal; *CS′*, backward extension of refracted ray; *BC*, projection of refracted ray on principal plane; *Z*, zenith: *S′*, image. Although *h* may become as great as *ZS*, internal reflection takes place before this point is reached, thus ending the "Parry arc."

points on the "Parry" arc, since it is one of perfectly general application in such problems, and seems to be about the most direct possible. In figure 3 the crystal

[1] MONTHLY WEATHER REVIEW, Jan., 1918, 46: 22; Science, 47, 170-171, 1918.
[2] MONTHLY WEATHER REVIEW, June, 1920, 48: pages 322-330.

and the observer may both be considered as located at the center of the celestial sphere C, because, owing to the indefinitely great radius of the sphere, rays from sun to observer and from sun to crystal may be considered as identical; the background extension of a refracted ray will then pierce the sphere at the point where the observer sees the resulting virtual image.

The rational horizon EE will then be the intersection of the plane of the top face with the celestial sphere; let $ZSMC$ be the plane of the vertical circle through the sun, $ZAPC$ a principal plane of the crystal indefinitely extended, and $ZS'C$ the plane of the vertical circle through the image; if SC be the incident ray making the angle ACS (measured by the arc h) with the given principal plane, then the refracted ray $S'C$ must also make the angle h with the principal plane. As the angle PCM varies from 0° to 90°, h varies from 0° to the angle ZCS (zenith distance of the sun); and from the laws of refraction and the known altitude of the sun the position of S' can be computed, by means of the chain of spherical triangles, for any assumed value of h.

THE GRAND JUNCTION HALO OF MARCH 3, 1906.

In the MONTHLY WEATHER REVIEW for March, 1906 (vol. 34, pp. 123–124), there is recorded an observation of a halo observed at Grand Junction, Colo., on March 3, 1906. The description given there is very meager, but the figures, here reproduced as figure 1, leave no doubt but that the upper and lower Parry arcs were present "The second drawing shows a slight change, there being a difference of about one hour between the two." The times of observation are not stated, and it is clear that the horizon is shown too low in the first figure in proportion to the scale of the halo, because the Parry arc, being produced by the same crystals as cause the upper tangent arc, merges indistinguishably with the latter at a comparatively low solar altitude. In the second figure, the Parry arc has disappeared, and an arc has become visible which is probably the sunward part of what Hastings calls the "lower oblique arcs passing through the anthelion."—*Edgar W. Woolard.*

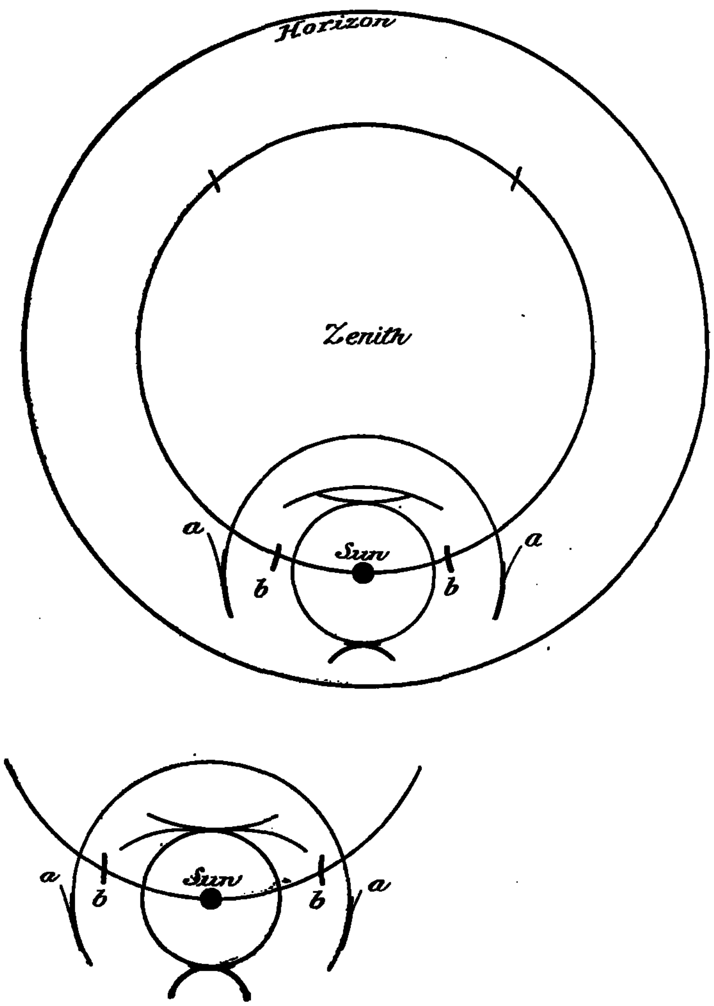

FIG. 1.—Halo observed at Grand Junction, Colo., March 3, 1906, by G. H. Ferguson.

OUTLINE SHOWING THE FORMATION OF THE ELEMENTS OF A HALO COMPLEX.

By EDGAR W. WOOLARD.

[Weather Bureau, Washington, D. C., July, 1920.]

I.—REFRACTION PHENOMENA.

Orientation of refracting edges.	Phenomena produced.	
	60° angle.	90° angle.
Vertical:		
Minimum deviation	22° parhelia	46° parhelia.
Other deviations	Tails to parhelia	Tails to parhelia. Supralateral and upper bitangent arcs. Infralateral and lower bitangent arcs.
Horizontal:		
Minimum deviation	Upper and lower tangent arcs to 22° halo.	
Other deviations	Upper and lower Parry arcs.	Circumzenithal arc. Circumhorizontal arc.
Inclined:		
Normal to planes through eye and sun—		
Minimum minimorum	22° halo	46° halo (?).
Other deviations	Glare outside halo	Glare outside halo.
In vertical planes through sun.	Arcs of Lowitz[1]	

II.—REFLECTION PHENOMENA.

Orientation of reflecting faces.	Phenomena produced.	
	Partial external or internal reflection.	Total internal reflection.
Vertical	Parhelic circle	Parhelic circle.
Horizontal	Sun-pillar	
Inclined	Oblique arcs of the anthelion (?).	
Multiple reflections	Anthelion and oblique arcs of the anthelion (?).	
Reentrant angles	120° parhelia (?)	

III.—MISCELLANEOUS.

Processes.	Phenomena.
Combinations of refraction and reflection	"Upper and lower oblique arcs passing through the anthelion." 120° parhelia (?). Paranthelic arc (?). Kerns arc (?). 90° halo (halo of Hevelius). 136° halo (Bouguer halo, false white rainbow).
Miscellaneous	90° parhelia. Vertical parhelia. Mock suns. Extraordinary halos. Secondary halos.

[1] See, however, S. Fujiwhara, On the Theory of Lowitz's Arc, Proc. Tokyo Mathematico—Physical Soc., ser. 2, vol. ix, pp. 502–515, 1918.