

ART. XXV.—*The Sun Glows*; by HENRY A. HAZEN.

(Read Feb. 16th, before the Philosophical Society, Washington, D. C.)

THE recent brilliant lighting up of the skies after sunset and before sunrise have attracted universal attention, mingled in many instances with not a little superstitious dread. Physicists have taken the matter in hand and have advanced the most diverse hypotheses for an explanation. One of these is that immense volumes of volcanic gas were ejected on Aug. 26, 1883, into the atmosphere from the Straits of Sunda, and that these glows have been due to the diffusion of this gas, and furthermore that this gas has so enveloped the earth as to keep in its summer warmth, so that a mild winter has resulted.

Another theory, which seems to have gained the most adherents of any, is that the volcanic eruption mentioned above filled the air to a great height with ashes and that the upper currents have distributed these ashes over the earth, thus causing an ash canopy, reflection from which results in the glow. This is the theory so ably advocated by Mr. Lockyer in *Nature*, and more recently by Mr. Upton in *Science*.

The seemingly unusual nature of the phenomenon, calling for an extraordinary explanation, has induced some to advance the theory that the earth in its orbit has encountered a stream of minute meteors or a cloud of cosmic dust, and that the glow

* Hartley's analysis gave (Ce, La, Di. Yt.)₂O₃ 61.69, P₂O₅ 24.64, Al₂O₃, Fe₂O₃, CaO, MgO with some P₂O₅ 1.93, SiO₂ 3.76, combined H₂O 7.50=99.52. The above excludes 5.69 impurities, *loc. cit.*, p. 214. Other analyses are given in the paper, in one of which 23.19 per cent. cerous oxide, and 2.09 yttrium oxide were obtained.

is due to reflection from these particles kept at a great height by electrical repulsion.

It is the purpose of this article to give:

1st. A general idea of the earliest appearances of the phenomenon. 2d. To describe what may be seen by an ordinary observer even to-day. 3d. To present the vapor theory and answer objections. 4th. To show why the "volcanic ashes" and "cosmic dust" hypotheses are untenable.

Remarkable sunset phenomena are reported as occurring on various dates at the following places.

	Date.	Place.	Lat.	Long.
1883, Aug.	28.	Mauritius	20° S.	57° E.
	30.	Maranhão, Brazil	2 S.	44 W.
Sept.	1.	New Ireland	5 S.	152 E.
	2.	Venezuela	10 N.	65 W.
	5.	Hawaii	20 N.	156 W.
	8.	Ceylon	7 N.	80 E.
	15.	South Australia	38 S.	143 E.
	20.	Cape of Good Hope	35 S.	20 E.
Oct.	8.	Florida	29 N.	82 W.
	19.	Yuma, Cal.	33 N.	114 W.
Nov.	9.	England	52 N.	0
	20.	Turkey		
	27.	British Columbia, Ala., Cal., Conn., Dak., Fla., Ga., Ills., Ind., Iowa, Kans., Me., Md., Mass., Mich., Mo., Neb., N. H., N. Y., N. C., Pa., Va., Wis., Germany, Italy, Spain, France, Sweden, England.		

Allowing for cloudiness, on certain days, it will be seen that before Sept. 8 a belt of the earth's surface 15° on either side of the equator was suddenly visited by the phenomenon. At first sight it might appear that there was a regular progression from the Indian Ocean westward, but on that supposition it would be hardly possible to explain why Venezuela should have seen the glow six days earlier than Ceylon, though somewhat farther north. The phenomenon might have been seen at Hawaii and even at Ceylon the last of August had it not been for cloudiness; and granting this it is plain that appearances might have been well nigh instantaneous over the regions near the equator. The glow was marked at Yuma on Oct. 19, 20 and 21, after which it ceased for a month. It was first seen in the eastern United States on Oct. 30, when the appearance was very brilliant; the same sight presented itself the next night, but after that it did not again appear as bright, though carefully looked for, until Nov. 27. On this night the spectacle in the southwest was grand and acknowledged by all as the finest even to the present time. The fire engines, at Poughkeepsie, N. Y., and at New Haven, Conn., were summoned to "quench the burning skies." On the succeeding night the scene was nearly the same. Since Nov. 28, the phenomenon has continued more or less brilliant, and with a few complete absences it has appeared down to the present.

A very remarkable fact is to be noted in connection with the display of Nov. 26 and 27, and that is, the sudden brightening over an immense region extending over half of Europe, over nearly the whole of the United States and British Columbia, though it had not been specially noted for about a month previous.

It may be interesting to note a few of the more detailed observations that have been made.

First. Just before and during the glow at night and after it in the morning, grayish, horizontally stratified, light clouds or striæ have appeared above the sun and have extended to right and left. These are invariably present with the glow, though the sky may be otherwise cloudless. On a careful examination, in the evening, these striæ will be usually found passing from a point 20 or 30 degrees to the left of the sun to the right and left and frequently overhead, reminding one forcibly of polar bands which are generally seen in eastern United States (where all these observations have been made) passing from S.W. to N.E.* In the morning in like manner striæ are seen passing above the sun and descending to the N.E. or N. and SW. or S. Often the directions of these striæ are confused and marked by cloud layers somewhat nearer the earth.

What are these striæ? On Feb. 1 at 5 P. M. with the sun 10° high the striæ were the plainest yet seen, many of them passing overhead in continuous lines to the NE.

On the right of the sun they were more distinct than on the left, and the radiated structure was very plain, emanating from the N.E. point of the horizon. The next morning the sky was clear, it was even possible to separate ϵ Lyræ into its components, the striæ were not visible at the first blush of morning, but a careful examination finally revealed them though very faint and of limited extent. On February 2d the appearances were about the same as the previous evening. In the S. a plain cirrus cloud was seen at a great height, its well-marked streaks dipped to S.E. and W.S.W., appearing as if at the outskirts of a great cloud system gradually advancing from S., though the actual motion of the cloud was from west to east. The streaks of cirrus while prominent did not have a sharp outline and were more or less broken up, while the striæ to the right were sharply defined and unbroken. At 5.30, the sun having set, the cirrus streaks overlapped the striæ and appeared plainly between them and the eye. At 5.35 the glow had begun in the horizon but was at a very low altitude, the striæ being unchanged, while a slight blush just tinged the cirrus

* The term "polar bands" is unfortunate as the striæ are parallel and the seeming polarity is due to perspective. The Germans use "Fallstreifen," and some such word might well be coined in English.

streaks. At 5.38 the former were unchanged, the latter had become a bright red. At 5.43 a slight rosy appearance was noted on the striæ, the color on the cirrus having slightly faded. At 5.44 the striæ were a clear rose color, while the cirrus was only bright near the sun, all color having disappeared from it at 50° to the left. At 5.48 the upper striæ near the sun were bright rose while nearer the horizon there was a deep red color, the cirrus were only seen as dark clouds against the bright red back-ground. The glow was very brilliant and lasted until 6.40. It is plain that the striæ are far above the cirrus clouds and appearances show that they are similar in formation. Whether these striæ are the cause of the glow or not is discussed later on.

Second. During the day with a cloudless sky the sun has appeared as if shining through a dense haze.

Third. On four occasions, January 4, 5, February 2 and 3, the moon was seen shining through seeming water vapor at a great height, the appearance being similar to that frequently noted at other times than the present. There was no halo in these cases, but a distinct ring uniformly bright about 30° in diameter.

Fourth. Several times when there was a plain cloud canopy, though rather light, and through openings in which the blue sky could be seen, the ordinary sunset phenomenon has been seen, upon this canopy, with glowing colors, and one-quarter or one-half hour afterward there has been the wonderful after-glow lasting till the end of twilight.

Fifth. Several times with a clear sky no glow has been seen, though it was quite prominent two or three evenings before and after. This intermittent nature of the phenomenon is regarded as one of its most important phases.

Sixth. The glow has not been quite as deep red in the morning as at night. On the morning of January 27, with a cloudless sky, a grand sight presented itself in the S.E. and E. At 5.50 a red glow first appeared, at 6.10, an intense red had extended to a height of 30° , though a rosy flush was seen even up to 50° , the whole eastern sky was lighted up. The striæ were confused by cloud layers near the observer. This first appearance faded away, but was followed at 6.45 by a still brighter glow. It is probable that this second glow was different from the regular sunrise appearance at 7.13. On February 3, at 6.15 A. M., the sky was very clear and the glow had already begun. At 6.25 the first glow was at its height, it then diminished until 6.35, when there was a very deep scarlet near the horizon. At 6.42 the red again developed rapidly, and at 6.47 the sight was fine, the lower deep red tapering to a rose at 25° altitude, and continuing up to 50° . At 6.55 only a faint

rose color was left. Thus the morning appearances differ from those in the evening, in that they show distinctly this double phenomenon. The two are identical to the observer and the second can be seen even in a perfectly cloudless day.

Seventh. Faint stars and clusters, notably Præsepe, have been easily seen even near the horizon. On January 27, in the morning, while the sky appeared covered by several distinct layers of cloud directly above the sun, yet it was possible to easily find Antares shining through the haze till twenty minutes before sunrise.

Seeking now a probable cause for the glow, it is suggested that at least three conditions are necessary to show the best results.

First. The sky must be clear or nearly so.

Second. There must be an abundance of reflecting, diffracting or absorbing material, as is shown by the well nigh world-wide appearances.

Third. There must be some force to carry the material to a great height or sustain it for a long time against the action of gravity. The lateness of the hour after sunset at which the after-glow disappears indicates that the material may be at a great height, and the fact of the later long continuance of the phenomenon shows that some force must be acting to keep up the particles.

The second condition is abundantly satisfied by the presence of watery vapor, ice crystals or frozen water particles under a peculiar form which is assumed in a rare atmosphere and at a low temperature. It must be admitted that the fact that watery vapor is universally and somewhat uniformly distributed over the earth's surface, and has always been found in great abundance at the extreme limits reached by aeronauts, is a most important one in this discussion. As to the peculiar form of frozen moisture or frost particles at high altitudes, the following experience of the writer may be of interest:

On Dec. 15, 1883, an ascent of Graylock, in Adams, Mass., was undertaken. This peak rises almost abruptly 2,700 feet above a plain which is itself 780 feet above sea level. The summit was reached at 7.30, and here a severe gale, estimated at fifty miles per hour, was experienced. The temperature was $7^{\circ}.1$ below zero and the air was completely saturated with vapor, the wet bulb, after most careful manipulations, reading about half a degree *higher* than the dry. While there seemed to be a grayish cloud overhead, absolutely no ice spiculæ or frost particles could be seen or felt. The sensation was almost a weird one, apparently a dense shadow in broad daylight, with nothing to cast it. That there were minute, invisible, frozen moisture particles, was plain from the beautiful appearance of all trees and shrubs which made it seem as if one had stepped

into an ocean of gigantic coral formations. The frost work was from .50 to .75 inch thick upon the branches and trunks of the trees. The frost work after a time formed on the coat of the observer as if accumulated by degrees. These frost particles were too minute to be seen directly, but could easily be recognized either by looking through a great depth or by the effect of the sun's light upon them.

It is not definitely known what causes the ordinary sunrise and sunset colorings, but it is certain that they may occur in all their magnificence in clear skies. The opinion generally held, that they are caused by the absorption of the rays at the blue end of the spectrum by moisture or dust particles, will not explain the present glows. It has been thought, however, that they may be explained if we consider them due to reflection from definite particles in the air. One difficulty in this is that we must assume that reflection and absorption would produce an effect precisely similar to the ordinary phenomenon. It may be said that the ordinary coloring may be caused by reflection, but it is a little singular that such an explanation has not before been suggested by meteorological authorities.

Under the third condition suggested above, some form of electrical action may be mentioned as amply sufficient to fulfill the requirements. We have no means of deciding the height at which frost particles are ordinarily sustained. Siemens has suggested that some form of vapor must be found at and beyond the limits of our atmosphere; however this may be, there must be some cause for so large an increase in the amount of frost particles in the upper regions of the atmosphere as to produce the present remarkable after-glows. That electrical action has been increased of late is evidenced by the behavior of electrical instruments in India immediately after the tremendous convulsion at Krakatoa. Also we note the recent increase in volcanic and earthquake phenomena over the earth, which it is well known is usually accompanied by electrical disturbances. The evidence from the sunspots also points in the same direction. The following table of mean monthly sunspot numbers is taken from "Science" for July 20, 1883. The observations have been made by Prof. D. P. Todd, of Amherst, Mass. I have added the observations since May, 1883, for comparison.

Table of mean sun spot numbers 1880-83.

	Month.	No.	Residuals.	3d Order of Means.	Residuals.
1880,	January,	11.5	— 12.9		
	February,	6.4	— 18.0	5.8	— 18.7
	March,	2.1	— 22.3	6.4	— 18.1
	April,	9.1	— 15.3	9.8	— 14.7
	May,	11.7	— 12.7	12.5	— 12.0
	June,	14.8	— 9.6	14.3	— 10.2
	July,	11.8	— 13.6	19.1	— 5.4
	August,	23.0	— 1.4	25.3	0.8
	September,	33.4	9.0	25.4	0.9
	October,	21.4	— 3.0	19.4	— 5.1
	November,	15.6	— 8.8	14.8	— 9.7
	December,	10.8	— 13.6	15.4	— 9.1
1881,	January,	18.5	— 5.9	19.8	— 4.7
	February,	19.9	— 4.5	26.3	— 1.8
	March,	31.9	7.5	30.6	6.1
	April,	36.5	12.1	29.6	5.1
	May,	20.4	— 4.0	29.4	4.9
	June,	34.5	10.1	32.8	8.3
	July,	34.4	10.0	33.9	9.4
	August,	36.0	11.6	30.1	5.6
	September,	25.7	1.3	24.6	0.1
	October,	21.5	— 2.9	21.3	— 3.2
	November,	19.8	— 4.6	20.1	— 4.4
	December,	21.0	— 3.4	20.6	— 3.9
1882,	January,	16.6	— 7.8	24.1	— 0.4
	February,	32.1	7.7	30.8	6.3
	March,	25.6	1.2	40.1	15.6
	April,	57.1	32.7	43.4	18.9
	May,	40.5	16.1	36.7	12.2
	June,	29.3	4.9	28.2	3.7
	July,	27.0	2.1	23.2	— 1.3
	August,	16.0	— 8.4	23.0	— 1.5
	September,	27.1	2.7	25.9	1.4
	October,	27.4	3.0	25.7	1.2
	November,	28.0	3.6	20.1	— 4.4
	December,	12.4	— 12.0	15.2	— 9.3
1883.	January,	12.2	— 12.2	15.4	— 9.1
	February,	19.7	— 4.7	19.0	— 5.5
	March,	15.0	— 9.4	22.4	— 2.1
	April,	35.8	11.4	22.4	— 2.1
	May,	7.4	— 17.0	26.3	1.8
	June,	34.6	10.2	35.2	10.7
	July,	48.7	24.3	35.5	11.0
	August,	24.0	— .4	32.0	7.5
	September,	31.1	6.7	34.6	10.1
	October,	41.4	17.0	37.1	12.6
	November,	35.5	11.1		
	December,	35.3	10.9		

This table shows an increase of spottedness in April, 1882, when probably the maximum of the present 11 years cycle occurred and after that a marked fall followed since July, 1883, by almost a steady rise. This fluctuation is still more plainly indicated by the residuals in the third order of means. If, as is generally supposed, an increase of solar spots indicates an increase of magnetical and electrical influences, we may con-

clude that the latter have increased within a few months, not manifested however in their usual manner.

Lastly, the arrangement of the "striæ" in the so-called "polar bands," attributed by Professor Loomis to electrical action, also supports the view here presented.

The three conditions, above, enable us to explain all the facts thus far developed. *First*: They must all be existent for the best display. If either of the latter two gradually or suddenly increase or diminish, it would account for the intermittent action. *Second*: Granting the presence of "frost particles" in abundance, the appearances can be easily accounted for, as they are similar to those we recognize when water or frost particles are the cause, whether produced by diffraction or otherwise. *Third*: The transparent nature of the frost particles enables us to see faint stars, which certainly an opaque or semi-opaque envelope would not do. *Fourth*: The detailed descriptions of glows January 27th, February 2d and 3d, show that the striæ or grayish, cloud-like, stratified forms are the true cause of the glows, for if there were other clouds there would have been on the evening of February 3d three distinct appearances: *First*, on the high cirrus; *Second*, on these clouds; and *Third*, on the material causing the after-glow, whereas there were only two distinct appearances. The fact that these are hardly visible in the morning is remarkable and seems to show a change brought about possibly by the effect of the sun's rays impinging, through the day hours, upon the frost particles. *Fifth*: If a progression in many instances be insisted on, and some of the observations plainly indicate this, it is easy to see that the meteorological conditions might bring this about in a movement of the frost particles.

It has been objected that, "The persistence of the phenomenon and its great extent show that it is not due to aqueous vapor." It has been shown, I think, that these very facts are in favor of this theory. A writer in Europe, after noting two specially marked occurrences, and finding that one of them immediately followed a "high" while the other a "low," decided that watery vapor had nothing to do with the glow. It is evident that in order to come to such a conclusion, it must be shown that vapor can be present only in connection with either a "high" or a "low," and does not act with both or independently of either. As a matter of fact most of the more brilliant after-glows have been seen in front of a high area, but this, it is reasonable to suppose, is not due to an intimate connection between the two or the necessity of the presence of the "high" to show the glow, but simply to the clearing of the air in front of the "high," which gives a more favorable opportunity for observation. It is objected that there is a distinct interval

between the ordinary sunset glow upon clouds or vapor comparatively near the earth and the later after-glow, whereas we should expect a continuous phenomenon if the vapor were uniformly distributed in depth. There is no evidence to show that the vapor is uniformly distributed; in fact Professor Vettin, of Berlin, has shown that the clouds have a tendency to arrange themselves in well defined layers at nearly constant heights. "Nature" for December 20th, 1883, gives the following table from his researches:—

Cloud.	Height in feet.
Lower	1600
Cumulus	3800
Cloudlets	7200
Under Cirrus	12800
Upper Cirrus	23000

The suggestion is also made that this indicates a geometrical progression in the heights, with a ratio of two. If such a ratio exists we can see that there might be a long interval between the highest and lower strata.

The most serious objection yet advanced however has been, that the rain-band spectroscope shows an entire absence of watery vapor. This objection is answered by the results of an investigation made by F. W. Cory of England, and recently presented to the London Meteorological Society. He found that a rainband as high as 70 per cent was followed by a *light* rain and one as low as 10 per cent was succeeded by a heavy snow, also that the spectrum is not affected previous to a snow fall except negatively, i. e. the rain-band diminished several days before a snow. He suggests that when vapor is transformed into snow crystals it does not cause a rain-band and that there is no doubt that when rain falls, after a low percentage of rain-band, it is due to either melted snow or hail. The report comes from Magdeburg that in the spectrum of the glow, uncommonly strong rain-bands were seen. This appearance was possibly due to a high temperature, prevailing at the time, which would fill the lower air stratum with water and not frost particles, and hence the spectrum, affected by this stratum, could reveal nothing as to the nature of the substance far beyond. The results of observations with the rain-band spectroscope are now called in question by many prominent meteorologists. In fact the unsatisfactory nature of the evidence may be easily shown to the satisfaction of any one possessing an instrument. If the spectroscope is first turned to the sky in any direction and afterward to a white wall fifty feet distant, it will be found impossible to distinguish between the appearance of the rain-band as shown by the whole atmosphere and by the layer fifty feet thick, and yet we find it insisted upon that the instrument

must be turned to different points in the sky. However this may be it would seem that the presence of an abundance of frost particles would not affect the spectrum as would the same amount of aqueous vapor above a temperature of 32° .

A most singular hypothesis has been advanced to account for the material in the sky, namely, that the volcanic action at Krakatoa on Aug. 26th and 27th ejected, into the atmosphere, immense masses of ashes which have been distributed by air currents over the earth's surface. Vivid accounts of the terrific nature of this convulsion, whereby a mountain island 2000 feet in height was perceptibly lowered, have been published by eye witnesses. The position of the volcano was in lat. $6^{\circ} 12' S$, long. $105^{\circ} 28' E$. By comparing this position with the dates and positions of the first appearance of the after-glows as already given, it would seem as though there had been a natural progression, but it has been shown that an instantaneous appearance will account for the phenomena as easily. The following are advanced as a few of the objections to this theory.

1st. There must have been sufficient material ejected to cover more than 135,000,000 square miles (the earth's surface 45° both sides of the equator). The attempt to add to this quantity by instancing isolated and slightly active volcanoes thousands of miles away can be regarded only as an endeavor to support a weak cause.

2d. There must have been currents of nearly equal force acting in *opposite directions* at the same height in the atmosphere, an impossible condition. Meteorology has established that if anything there is a steady current in the upper regions from west to east.

3d. The upper currents must have had sufficient velocity to carry the ashes a distance of 12,000 miles in 150 hours or at a rate of 80 miles per hour toward the *west*. We know little of velocities of air-currents at great heights, but they are probably slight. The summer velocity on Mt. Washington, 6299 feet above sea, is less than 30 miles per hour, while on Pike's Peak, 14,134 feet in height, it is only 20 miles per hour. The conditions certainly are very diverse at the two stations and it is possible that the Mt. Washington velocities are 15 per cent too high, but, allowing for these, there seems to be a possibility of a gradual diminution in wind velocity at increasing heights above the earth's surface.

4th. That the ashes must have been mechanically distributed first along a belt near the equator, and afterward, without addition except possibly of a meager character, the currents must have been sufficiently uniform over the whole earth, to have borne them north and south to above latitude 45° . This is well nigh incredible. It seems probable that in a few

radial lines from Krakatoa, ashes could have been carried 1500 or 2,000 miles, and some sporadic cases even greater distances. Professor Loomis in his *Meteorology* gives an instance in which volcanic ashes were carried 1200 miles in a single direction, nearly parallel to the equator, but it is more than likely that these were carried in comparatively narrow streams, and that almost the entire mass of matter ejected from a volcano returns to the earth within a few hundred miles. A good illustration of the nature of a stream of volcanic ashes is given by Mr. Whymper, in a recent number of "*Nature*." He gives a description of a cloud of ashes poured forth from the crater of a volcano, carried in a stream in one direction and afterward in another at right angles, but that there was no uniform distribution is plainly shown by the narrative.

Fifth. That the intermittent nature of the phenomenon precludes the idea of a dust envelope.

Sixth. That ashes are opaque while the appearances indicate great transparency.

The finding of a substance on the windows of a house in Holland, after a great wind and rain storm, which presented a similarity to volcanic ashes, is well known. This evidence must be accepted with caution, however, and it should be shown that it could not have come from the neighborhood, and besides it should all the more be found in other places. Similar substances have fallen at a locality in Spain, but the examiner of them candidly admits that they may have come from the region about.

The theory that the dust has come from space removes many of the objections before mentioned, and seems more satisfactory. The well nigh instantaneous appearance, the last of August and November, gives color to this hypothesis. The other appearances in September and October, at widely separated dates, seem fatal to it however, and besides it is difficult to consider that there were two clouds of dust into which the earth entered.

It is a matter of satisfaction that the phenomenon has attracted so much attention, and called out so many careful observations. These observations should be recorded, and especially any unusual development should be noted. A study of the cloud conditions as a whole, over the earth, will give an additional means of carrying on the discussion. The absence of auroral phenomena and magnetic disturbances at a time of sunspot activity is remarkable. The apparent surprising absence of all unusual appearances on Mount Washington and Pike's Peak demands an explanation. On the former peak a glow was noted December 2d.

While all explanations of the glows are more or less matters of conjecture, yet the field of conjecture is believed to be nar-

rowing, and we may hope ultimately to reach a satisfactory conclusion.

February 3, 1883.

NOTE—February 6th.—“Nature” for January 17, 1884, contains striking corroboration of some of these views. From Honolulu comes a note, that during November the glow somewhat diminished, but since November 25, they have again increased in marked degree. A note from near Warsaw, Russia, gives November 30 as the date of an unusual brightening. Another observer in Freiburg, Baden, reports brilliant red glow, on the morning of January 10th. The morning of January 11th, with a clear sky, the display was confidently expected, but very surprisingly it did not appear at all, the sun rising after a twilight of pale yellow.” In the evening clouds arose in the west, at first showing the red marginal coloring of ordinary sunsets, but later on there came again, distinctly higher than even the cirri, a very brilliant and lasting red luminosity.