OBSERVATION OF THE TOTAL SOLAR ECLIPSE OF JANUARY 3, 1908: A BOLOMETRIC STUDY OF THE SOLAR CORONA

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By invitation of Director Campbell, of the Lick Observatory, an expedition in charge of the writer was sent by the Smithsonian Institution to join with the Crocker Eclipse Expedition to Flint Island. In all matters of transportation, subsistence, and companionship the writer and his assistant, Mr. A. F. Moore, were cared for by Director Campbell as if members of his own staff; but the expenses of the Smithsonian party were paid in full by the Smithsonian Institution.

Narrative

The writer left Washington on November 7, 1907, necessary equipment, comprising 14 boxes of apparatus, having preceded him on the way to San Francisco. A stop was made at Pasadena, California, in order to ascend Mount Wilson and make there certain comparisons of readings between a pyrheliometer which was carried as hand baggage and instruments of the Smithsonian Astrophysical Observatory stored on Mount Wilson. Additional small pieces of apparatus were taken from Mount Wilson and a few supplies were procured in San Francisco. According to previous arrangement, the provisions and camping outfit for the stay on Flint Island were procured by Director Campbell. At San Francisco the Flint Island eclipse party, comprising Director and Mrs. Campbell, Professors Perrine and Aitkin, and Doctor Albrecht, of the Lick Observatory; Professor Lewis, of the University of California; Mr. Moore (a student at the University of California), and the writer, besides some friends of members of the expedition who were to accompany us as far as Tahiti, embarked on the steamship *Mariposa* November 22, 1907. We had a calm and pleasant voyage of 12 days to Tahiti, where it was expected that the gunboat *Annapolis*, under command of Governor Moore, of Tutuila, would be in waiting to convey the expedition to Flint Island. Owing to a broken steam pipe, the *Annapolis* was delayed in reaching Tahiti until two days after our arrival, and owing to the making of necessary repairs, the start for Flint Island was deferred until the evening of December 7. About noon of December 9 the island was sighted, and soon a boat was seen to leave its shore to meet us. On near approach it proved to contain the English manager, Mr. Hawk, and a half dozen native boatmen. Our landing was immediately begun, as the circumstances were unusually favorable, owing to the complete absence of surf—a condition which Mr. Hawk said was not apt to be met with three days in a year.

Flint Island, a low coral island lying in latitude 11°½ S., longitude 152° W., is about two and a half miles long by half a mile wide, and only 24 feet above sea-level at the highest point. It is surrounded by a fringing reef, upon which the surf beats so strongly on the eastern, or windward, side that landing is there impracticable. An opening has been blasted out of the reef on the western, or leeward, side to facilitate the shipping of copra, or dried cocoanut pulp, which is the only export. The water becomes deeper so rapidly beyond the reef that there is no anchorage for ships, although it is safe to cruise back and forth within a quarter of a mile of the shore. Favored by a bright moonlight, the equipment of the expedition, comprising over 300 separate packages and weighing more than 25 tons, was all taken ashore by the natives of the island and the Samoans of the *Annapolis* by 9 o'clock p. m. of December 9.

Our first night was spent on the veranda of the manager's house, where we slept most comfortably, lulled by the swaying branches of the cocoanut palms and the incessant murmur and croaking of birds. Toward morning the sudden coming of a smart shower made us glad that we had worked late, tired though we were, and had thoroughly secured our equipment. Two days later we learned how fortunate we had been in getting ashore so easily, for without much wind or roughness at sea the surf rose rapidly on the western side of the island and finally reached almost to the highest land of all. At this time our surf-boat was floated away and narrowly escaped loss at sea.

The Lick Observatory camp was located in an open space of the cocoanut grove near the manager's house, but as the writer desired to make measurements of the brightness of the sky, he preferred to locate the Smithsonian apparatus on the beach. After partly deciding upon a place nearly a quarter of a mile south of the main camp, he at length chose a point about 1,000 feet north of the camp and near the landing. As the event proved, the whole fortune of the

Smithsonian expedition hung upon this choice, for on January 3, the day of the eclipse, a rain-cloud almost hid the total phase from view, and rain would probably have fallen throughout totality at the station first proposed.

In the three and a half weeks spent on Flint Island the apparatus was put in the most perfect condition, many practice rehearsals were carried through, measurements were made of the brightness of the sky, the sun, and the moon, and a meteorological record was kept by Mr. Moore. At the suggestion of Mr. Rathbun, Assistant Secretary in charge of the U. S. National Museum, the writer collected a number of kinds of shells and corals for the use of that Museum.

Among the interesting social events were the coming of the English eclipse party of Mr. F. K. McLean and the celebration of Christmas, New Year's, and a marriage anniversary. On Christmas day Rev. Mr. Walker, of the McLean party, read a service at 9 a. m., and in the evening a company of seventeen English-speaking people from England, Australia, New Zealand, Tahiti, and the United States had a turkey dinner together on this coral island of the South Pacific. On New Year's evening a prize poetic contest was enjoyed.

After the eclipse the expedition left Flint Island on January 5, reached Tahiti on January 7, and embarked for San Francisco January 13. During the stay at Tahiti on the outward trip the presence of so many Americans had been taken advantage of by Consul Dreher as a fitting time to celebrate the completion of the new consulate at Papeite. Our stay on the return was also made pleasant by the attentions of the consul, and by trips to the interior and along the coast to the home of Chief Tati Salmon. The scenery of Tahiti is exceptionally beautiful and fine, for high mountains are broken at many points by nearly vertical precipices thousands of feet high, yet clothed from top to bottom by luxuriant tropical verdure. Clear streams run down the steep-sided valleys and water-falls of more than 600 feet sheer fall are found upon them. Our visit to Chief Tati Salmon was made most interesting by his recounting of ancient stories of the islands and by the serving of native dishes cooked on hot stones by the seashore.

Our voyage to San Francisco, while unpleasantly rough, was made without mishap to the expedition, and the writer reached Washington on February 1, 1908.

Objects and Methods

We proposed to measure with the bolometer the intensity of the radiation of the solar corona and to determine the quality of coronal radiation as compared with that of the sun.

In the year 1900 the first bolometric observations of the corona were made by Smithsonian observers,[1] and from these observations certain inferences were drawn by different authors as to the quality of the radiation of the inner corona.

All bodies, by virtue of their temperatures, emit radiation; but it is only when the temperature is fairly high that any considerable part of the radiation is visible. The higher the temperature the larger becomes the proportion of the radiation caused thereby which is visible.

All bodies exposed to radiation reflect some fraction of it diffusely, but thereby generally alter the quality of complex radiation. When the reflecting bodies are particles whose diameters are small compared with the wave-length of light, they reflect the shorter wave-lengths better than the longer ones, and thus tend to render a larger proportion of the radiation visible. Larger particles and gross bodies, like the moon, by reflecting, generally alter the quality of radiation in a way to diminish the proportion visible.

Visible rays are sometimes emitted by bodies which are apparently far below the temperature of incandescence, as in the cases of electrical discharges and of luminous insects. Such radiation may perhaps be almost wholly visible, without much intensity in the infra-red spectrum.

In view of these considerations and others, the inferences drawn by the writer from the bolometric study of the corona made in 1900 were contrary to the view that the radiation of the inner corona is produced mainly by the incandescence of matter heated to high temperatures by reason of its proximity to the sun, and more favorable to supposing the coronal radiation due largely to luminescence, or perhaps to the reflection of solar radiation by small particles. Arrhenius came to a different conclusion; but, as pointed out in the reference last cited, he misinterpreted the position of the bolometer in the coronal image.

The bolometric observations at Flint Island were designed to test the inferences above referred to and to measure more definitely the quantity and quality of the coronal radiation.

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[1] See Astrophysical Journal, vol. 12, pp. 71–75; also pp. 366–375, 1900. "The 1900 Solar Eclipse Expedition of the Astrophysical Observatory of the Smithsonian Institution," pp. 22–26. Washington, Government Printing Office, 1904. Lick Observatory Bulletin No. 58. Astrophysical Journal, vol. 20, pp. 224–231, 1904; Astrophysical Journal, vol. 21, pp. 194–195, 1905.

Apparatus

A concave mirror of 50 centimeters diameter and only 100 centimeters focus, mounted equatorially and driven by a clock, served to produce a very intense image of the corona.[1] A small guiding telescope was attached to the mirror frame, so that the observer might point the mirror toward any desired object. In the focus of the mirror was placed the bolometer. A glass plate three millimeters thick was fixed close to the bolometer, between it and the mirror, so that the radiation examined was thereby limited to wave-lengths less than about 3μ. This device prevented any exchange of rays of long wave-lengths between the bolometer and the sky, such as produced negative deflections when the bolometer was exposed toward the corona in 1900.[2] The bolometer had blackened platinum strips 8 millimeters long and 0.7 millimeter wide and of 0.5 ohm resistance. A metal diaphragm with circular aperture of 1 millimeter diameter was fixed between the glass plate and the central bolometer strip, so as to limit the region of the corona examined at each observation to an angular area of about 3′ of arc in diameter.

About 10 centimeters in front of the bolometer was a self-closing blackened metal shutter which cut off the beam excepting when designedly opened. The opening of this shutter therefore exposed the central part of the bolometer to such rays as are transmissible by glass. Between the shutter and the glass plate, and close to the latter, was a special screen composed of a thin stratum of asphaltum varnish laid on one side[3] of a plane parallel glass plate 3 millimeters thick. This screen was held out of the beam by a spring, except when designedly interposed. Its property, when used, was to cut off nearly all the visible part of the radiation, while transmitting nearly all of the infra-red rays transmissible by glass. The transmissibility of this screen for rays of different wave-lengths follows:

	μ	μ	μ	μ	μ	μ	μ	μ	μ	μ
Wave-length......	0.50	0.55	0.60	0.65	0.70	0.80	1.00	1.20	1.60	2.00
Transmissibility. .	0.00	0.01	0.04	0.10	0.20	0.41	0.66	0.80	0.90	0.92

[1] The mirror was freshly silvered and polished on the day before the total eclipse.

[2] Negative deflections in those experiments were due to the fact that the card screen used was warmer than the effective temperature of the sky, not, as Deslandres intimated, because any kind of rays cools rather than warms when absorbed.

[3] The side nearest the bolometer.

By interposing this absorbing screen the proportion of the observed radiation which lay in the infra-red spectrum could be roughly determined. Various trials made on Flint Island showed that ordinary sun-rays comprised from 29 to 37 per cent of rays transmissible by this screen, depending on the humidity of the air and the altitude of the sun; whereas sky-rays were only about 20 to 25 per cent transmissible. Moon-brightness (and by this is meant reflected sun-rays, not rays proper to the moon itself, for such were eliminated by the glass plate) was examined on one occasion and showed a transmissibility of about 50 per cent.

Several diaphragms were provided for graduating the aperture of the concave mirror. The apertures of these diaphragms were knife-edged, and those of less than 1 centimeter diameter were adjusted to lie within 3 millimeters of the silvered surface of the mirror. Allowing for the portions of the mirror shaded by the bolometer and its adjuncts, the apertures available were as follows:

Area (sq. cm.).........	1,618.0	283.0	62.0	0.316	0.077
Factor.................	1.0000	0.1750	0.0383	0.000195	0.000048

The equatorial was set up at Flint Island, on the beach, at about 12 meters' distance from the galvanometers used for observing the indications of the bolometer. Two galvanometers were provided, exactly alike in resistance and general construction, and arranged so that if at the last moment any accident should happen to one, the observer might pass at once to the other.[1] A thatched hut shaded by palm trees sheltered the galvanometers and their appliances and was found to give most satisfactory protection both from heat and rain. The galvanometers were each of 1.5 ohms total resistance, composed of 12 coils all connected in series. The needle systems, of 30 needles each, had mirrors 1 mm. by 1.2 mm. and weighed complete 0.011 gram each. Acetylene lamps were employed as light sources, and the images of the narrow flames were read on ground-glass scales 90 centimeters in front of the galvanometers. Resistances of 3, 8, 17, 45, 200, and 1,000 ohms, respectively, could be put in series with either galvanometer to reduce its deflections if required. The corresponding factors of reduction are 2.0, 4.0, 6.0, 13.1, 60.0, and 300. These numbers were obtained by actual trial.

The Wheatstone's bridge of the bolometer comprised the two platinum strips of 0.5 ohm each and two coils of 5.0 ohms each.

[1] This prudent measure was suggested by Mrs. Abbot.

These were inclosed in a wooden cylinder 7 centimeters in diameter and 18 centimeters long, itself shaded by a ventilated double-walled brass shield. A battery of 4 Gladstone-Lalande cells was used, furnishing a current of 0.4 ampere. This battery was located in the hut, and means for exactly balancing and trying the sensitiveness of the bolometric circuit were provided by joining to one galvanometer terminal and one battery terminal an adjustable resistance of about 500 ohms, acting as a shunt around one of the 5-ohm coils. It proved necessary to shade the copper cables connecting the bolometer and the apparatus in the hut, but after this was done the whole apparatus worked very satisfactorily, without prejudicial drift or wiggle of the galvanometer spot. When considerable changes of the pointing of the equatorial were made, it was generally necessary to alter the balancing resistance slightly, as would be expected in consideration of the changed inclination of the bolometer strips. During the eclipse the time of single swing of the galvanometer was 1.9 seconds, and a change of 1 ohm in the balancing resistance produced 250 millimeters deflection. This indicates that a rise of temperature of one bolometer strip of about 0.00001° C. would have produced 1 millimeter deflection at that time. These, of course, are far from the most sensitive conditions possible,[1] but were regarded as good for a temporary installation.

The attention of the reader is invited to the following improvements in the apparatus of 1908 as compared with that of 1900:

1. One mirror replaces seven.

2. The uncertain exchange of radiations of long wave-length between the bolometer and sky is eliminated by interposing glass.

3. Each observation is limited to a comparatively small angular area, well defined in position.

4. An absorbing screen for indicating the quality of the rays is introduced.

5. Means are employed for comparing in intensity the rays of the sun, the sky, and the corona.

During the eclipse the writer was charged with pointing and manipulating the equatorial, Mr. Moore with reading the galvanometer, and Chief Yeoman Edward M. Chase, of the *Annapolis,* with giving time signals and exposing two small cameras.

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[1] In Washington, with a scale distance of 4 meters and a time of single swing in a vacuum galvanometer case of 7 seconds, a deflection of 0.1 millimeter has been measurable. This corresponded to a rise of temperature of 0.00000001.

Preliminary Observations

Meteorological

The sky conditions were seldom constant for any great length of time on Flint Island, so that pyrheliometer readings were not often attempted. On December 29, at noon, the intensity of solar radiation at the camp was 1.423 calories per square centimeter per minute, with fine blue sky.

Mr. Moore observed on Flint Island the temperatures of wet and dry bulb thermometers, barometric pressure, direction, and approximate velocity of the wind in miles per hour, and cloudiness, at the hours 7 a. m., $11^h\ 18^m$ a. m., 5 p. m., and 9 p. m., each day from December 10, 1907, to January 4, 1908. Without giving individual values, excepting for January 3, a summary of the mean results of his observations follows. The column marked P indicates the pressure of aqueous vapor at the earth's surface in centimeters of mercury, and that marked Q the corresponding total precipitable water in a vertical column of the atmosphere 1 sq. cm. in cross-section, according to Hann's formulæ.

Time.		Temperature.		P.	Q.	Barometric pressure.	Direction of wind.	Velocity of wind.	Cloudiness.
		Dry bulb	Wet bulb.						
		°C.	°C.	*cm.*	*cm.*	*In.*			
7 a. m.	Jan. 3 ..	27.0	24.7	2.53	5.82	30.11	....	0.	0.8
	Mean ..	26.75	24.23	2.48	5.70	30 078	E	7.8	0.78
$11^h\ 18^m$	Jan. 3 ..	....	....	....	....	....	....	....	....
	Mean ..	28.83	24.69	2.74	6.30	30.049	E.	11.7	0.63
5 p. m.	Jan. 3 ..	28.2	25.0	2.68	6.16	30.05	......	0.	0.9
	Mean ..	27.09	24.22	2.52	5.80	30.012	E.	5.6	0.62
9 p. m.	Jan. 3 ..	26 5	24.5	2.47	5.68	30.14	N. E.	5.	0.0
	Mean ..	26.11	23.90	2.40	5.52	30.068	E.	8.4	0.53

Bolometric

The eclipse observations are of much more interest when considered along with other observations which have been made of the relative brightness and quality of sun, sky, and moon rays.

Sun-brightness, Sky-brightness, and Moon-brightness [1]

On December 29, 1907, one of the very few days during our stay on Flint Island when the sky was mostly free from clouds and of a

[1] I propose to employ these terms for brevity, to mean the intensity of the radiation of the sun, sky, or moon transmissible by glass, and therefore of less wave-length than 3 μ.

good blue color for a considerable time, numerous measurements were made with pointings on the center of the sun's disk and on many parts of the sky. In these measurements the full aperture of the concave mirror was employed for the sky, and the "0.316" aperture for the sun. Sun-brightness was further reduced by interposing in the beam a rotating disk from which a sector of .045 of the whole circle had been cut. Eight ohms' resistance was placed in series with the galvanometer, under which circumstances 1 ohm change in the balancing resistance produced 55 mm. deflection. The measurements were begun about 9^h 40^m a. m. and continued till 10^h 40^m a. m., local time, so that the sun was 20° to 40° from the zenith.

Reserving for another publication a detailed study of these and other comparisons of sun and sky brightness, it will be sufficient here to state that the relative brightness of sky and sun, equal areas being measured, varied from 0.0000031 at distant parts of the sky to 0.0000140 at 20° from the sun. The average value was 0.0000062. It was impossible to secure accurate observations nearer the sun than 20°, because the mirror could not be properly shaded from the sun in such cases, and the diffused reflection of sun-brightness would have masked the true sky-brightness.

Measurements made on Mount Wilson, in California,[1] in 1905–6 showed that the average ratio at that altitude was about 0.0000015, so that the sky at sea-level appears to be, roughly, four times as bright as on Mount Wilson.

From measurements made on December 27 at 3^h 30^m a. m., the moon-brightness was about 0.0000012 of sun-brightness; but this ratio can only be regarded as roughly approximate,[2] and likely to be altered with the haziness or humidity of the air as well as with the altitudes of the sun and moon.

Quality of Sun-brightness, Sky-brightness, and Moon-brightness

On December 26, with the sun about 40° from the zenith, the ratio of the sun-brightness transmissible by the asphaltum screen to the total sun-brightness was found to be 0.366, while for zenith sky-brightness the result came out 0.248. Owing to the change of humidity from time to time, with consequent large alterations of the

[1] Altitude, 1,800 meters.

[2] This ratio is not directly comparable with the determinations which different observers have made of the relative photometric measures of the light of the sun and moon, nor, on the other hand, with determinations of the relative amounts of the total radiation of the sun and moon.

intensity of the infra-red spectrum, ratios like these just given are not to be regarded as constants. In order to avoid errors from this cause, care was taken on eclipse day to determine the transmissibility of sun-brightness immediately before and after totality, as will appear in its place.

On other days before the eclipse, values of the transmissibility ratio for sun-brightness were obtained, ranging from 0.29 to 0.37.

On the morning of December 27, at 3^h 30^m a. m., the transmissibility of the moon-brightness was found to be 0.50.[1] It is very significant to note that the day sky and the moon, both reflecting sun rays, alter the quality of sun rays in opposite directions and in such marked degrees. The blue quality of the sky-brightness, as Lord Rayleigh has shown, is probably due to the fact that the reflection takes place from particles small compared with the wave-length of light, and principally perhaps from the molecules of air themselves.

In view of the data just given, we should suppose that the brightness of the solar corona, if we imagine it to be caused merely by the reflection of ordinary sun rays, would be more transmissible to the asphaltum screen than sun-brightness, if the reflecting particles are of gross magnitude, like those composing the surface of the moon; but less transmissible than sun-brightness, on the other hand, if the reflecting particles are minute like the molecules of gases.

Observations on Eclipse Day

The approach of totality was uncommonly exciting on this occasion. Early in the morning the sky was overcast with high clouds, but these gradually grew thinner, so that after 9 a. m. the prospects indicated a streaky sky containing something almost too thick for haze, but almost too thin for cirrus clouds. These prospects were fulfilled exactly during totality, but in the quarter of an hour next preceding a thick cloud came up, rain fell fast from 11^h 08^m to 11^h 14^m, and the view of the sun became clear of the rain-cloud only 15 seconds before totality, at the Smithsonian station. The rapid change from fair prospects to completely discouraging ones and the return of good conditions just at the critical time will long be remembered. Our entire immunity from rain during totality was due to the fact that our station was about 1,000 feet north of the one occupied by the Lick Observatory. Second contact was observed by the writer, and recorded by Yeoman Chase at 11^h 15^m $7.^s5$, local civil time.

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[1] See also Langley's comparison of the visible spectra of the sun and moon. Memoirs National Academy of Sciences, vol. III, 1884, p. 21.

At about $10^h\ 55^m$ and $11^h\ 45^m$ the following two series of observations were recorded on the brightness of the center of the sun's crescents visible respectively before and after the eclipse. In each series there was employed the "0.077" aperture, and also a series resistance of 200 ohms in the galvanometer circuit. The table includes actual readings on the galvanometer scale before and after opening the shutter of the bolometer, sometimes with, sometimes without, the asphaltum screen. In reading the galvanometer, the position of steady condition is first noted; then the furthest excursion of the spot of light after opening the shutter, which corresponds to the first swing of the galvanometer. In computing actual deflections, no account has been made of drift of zero between the steady position and the end of the first swing, because this interval is only 2 seconds, and the drift was at no time rapid enough to be of import in this brief interval. During all these measurements of sun-brightness the time of swing of the galvanometer was the same as employed during the total eclipse. The places on the sun may be regarded as having been 0.7 radius distant from the center of the solar disk.

Measurements at $10^h\ 55^m$

Closed.	Open.		Deflection.	
	No screen.	Screen.	No screen.	Screen.
cm.	*cm.*	*cm.*	*cm.*	*cm.*
16.0	22.5	....	6.5	....
16.0	....	18.2	....	2.2
16.3	22.8	....	6.5	....
16.3	....	18.5	....	2.2
16.5	23.1	....	6.6	....
16.5	....	18.8	....	2.3
16.6	23.3	....	6.7	....
16.6	....	18.7	....	2.1
	Means..........		6.60	2.20

Ratio, 0.333

Measurements at $11^h\ 45^m$

Closed.	Open.		Deflection.	
	No screen.	Screen.	No screen.	Screen.
cm.	*cm.*	*cm.*	*cm.*	*cm.*
8.4	15.3	....	6.9	....
8.6	....	10.9	....	2.3
8.4	15.3	....	6.9	....
8.5	....	10.7	....	2.2
8.4	14.6	....	6.2	....
8.4	....	10.7	....	2.3
8.4	15.4	....	7.0	....
8.5	....	10.7	....	2.2
8.5	15.5	....	7.0	....
	Means............		6.80	2.25

Ratio, 0.331
Mean transmissibility of sun-brightness, 0.332

Measurements on the Corona

In the field of the finder telescope were cross-threads, two of which intersected in the center, making an angle of 75°. One of these threads was adjusted along the line of diurnal drift of the sun, as found by stopping the clock of the equatorial. When the moon's image was adjusted tangent to the threads, there were four positions available, according as the moon occupied one of the obtuse angles or one of the acute angles between the intersecting threads. During the eclipse, measurements were made of the corona-brightness at the two positions of tangency in the obtuse angles, and one measurement was made in one of the acute angles. Besides these three positions, two others were employed, situated 1.5′ of arc beyond the extremities of the moon's east and west diameter, and one position in the center of the dark moon, making six in all. In view of the symmetrical character of the results to be given, and of the uncertainty of precise setting on so small an image with the bolometer, it seems unnecessary to specify the first three positions more definitely than to add, that in the two positions of obtuse angle tangency the bolometer was central on points 4′ of the arc beyond the extremities of a lunar diameter inclined 52.5° to the east and west diameter, and in the position of acute angle tangency the distance from the moon's limb was about 12′ of arc.

Let the six positions be designated in the order described above as Positions I, II, III, IV, V, and VI.

The measurements are as follows:

POSITION I

Closed.	Open.		Deflection.	
	No screen.	Screen.	No screen.	Screen.
cm.	*cm.*	*cm.*	*cm.*	*cm.*
11.3	14.2	....	2.9	....
11.2	14.5	....	3.3	....
11.2	....	12.4	....	1.2
11.4	....	12.0	....	1.2
	Mean....	....	3.1	1.2

Ratio, 0.387.

POSITION VI

No deflection whatever.

POSITION II

Closed.	Open.		Deflection.	
	No screen.	Screen.	No screen.	Screen.
cm.	*cm.*	*cm.*	*cm.*	*cm.*
7.1	10.2	....	3.1	....
6.9	....	7.9	....	1.0

Ratio, 0.323

POSITION III

No deflection whatever.

POSITION IV

Closed.	Open.		Deflection.	
	No screen.	Screen.	No screen.	Screen.
cm.	*cm.*	*cm.*	*cm.*	*cm.*
13.1	23.9	....	10.8	....
13.6	....	17.3	....	3.7

Ratio, 0.343

Position V

Closed.	Open.		Deflection.	
	No screen.	Screen.	No screen.	Screen.
cm.	*cm.*	*cm.*	*cm.*	*cm.*
17.8	27.7	....	9.9	....
19.0	....	22.8	....	3.8
Ratio, 0.384				

On account of the number of observations, the result in Position I is entitled to twice as much weight as that in Position II; and on account of the larger deflections observed, the results in Positions IV and V are regarded as each of twice the weight of those in Position II. It is not thought that the variations of the ratio of transmissibility between the several observations just noted are beyond the probable errors of the single determinations, so that without distinguishing separate positions, the weighted mean result for the transmissibility of the inner corona-brightness may be regarded as 0.364. For positions I, II and IV, V, taken in pairs, the means are 0.366 and 0.362 respectively.

In order to determine the intrinsic corona-brightness as compared with sun-brightness, we must first multiply the average solar deflections observed before and after the eclipse by the two factors appropriate to allow for the ratio of size of mirror apertures employed and for the introduction of series resistance in the galvanometer circuit respectively. Performing this reduction and introducing also the data of sky-brightness already given, we obtain the following values based on a sun-brightness of 10,000,000:

Sun near zenith (Flint Island)	10,000,000
Sky 20° from sun (Flint Island)	140
Sky distant from sun (Flint Island)	31
Sky average (Flint Island)	62
Sky average (Mt. Wilson)	15
Corona Positions IV and V	13
Corona Positions I and II	4
Moon about 50° zenith distance (Flint Island)	12 (?)

Discussion of the Results

When we recall the extreme brightness of the sky within a single degree of the sun as compared with that 20° away, and consider also the figures just given, the proposal to observe the carona without an eclipse seems an unpromising one.

From the figures just given it appears that the corona of 1908 equaled the moon in radiation transmissible by glass only at the brightest observed part of the inner corona. Referring to the conclusions made by the writer from the bolometric observation of the eclipse of 1900, it will be recalled that it was assumed by him that the region of the corona then observed was equally as bright as the moon visually. It now seems probable that this was not so, and accordingly the argument he made for an exceptional richness of visible light in coronal radiation, which depended on the assumption just referred to, is weakened. In actual fact the coronal radiation proves to be almost, but not quite, as rich in visible light as the ordinary solar radiation coming from points 0.7 radius from the center of the sun's disk, as shown by the measurements of 1908 made with and without the screen.

Probable Nature of the Corona

The nature of the radiation of the inner corona has been supposed by some to be principally reflected solar radiation; by others, principally due to the incandescence of particles heated by reason of their proximity to the sun; by others, principally luminescence, perhaps similar to the aurora; and by some as a combination of all these kinds of radiation.

A satisfactory theory of the corona must take cognizance of the following facts at least:

1. The color of the corona does not appear to change at varying distances from the limb of the sun, and the transmissibility of its rays to the asphaltum screen is the same at 1.5′ and 4′ from the limb.

2. Its brightness is very small and falls off rapidly with increasing distance from the limb.

3. Its spectrum is mainly continuous near the limb, but shows dark Fraunhofer lines, more and more distinctly, at increasing distances therefrom. A few not very conspicuous bright spectral lines are present near the limb and perhaps in the outer corona also.

4. Its light is polarized in the outer regions, but polarization grows less marked, and at length disappears near the limb.

5. Its brightness is almost, but not quite, as little transmissible to the asphaltum screen as that of the sun itelf, and is far less so than the reflected brightness of the moon, but far more so than the reflected brightness of the sky.

6. Any kind of matter so near the sun must be hot and must also reflect solar rays.

7. There is no evidence of high pressure in the corona.

The considerations (3), (5), and (7), taken together, are hard to satisfy; for if the inner corona were hot enough to give out a spectrum of incandescence satisfying (5), the matter composing it must be gaseous, if it is like any matter we know of.[1] Accordingly we should expect a bright line spectrum like that of the chromosphere if the inner corona shines chiefly by incandescence,[2] and, furthermore, we should expect its rays to increase in transmissibility to the screen and grow red to the eye with increasing distance from the sun.

If we may suppose that the temperature of the corona is everywhere low enough to allow solid or liquid particles to be formed, then all the specifications excepting (3) are easily satisfied by the hypothesis of a corona of reflection.[3] Our knowledge is not sufficient to enable us to prove that the particles even of the inner corona would be too hot to be mainly liquid (that is to say, above 3,000° to 3,500°). If the particles were all gaseous, the rays reflected would probably be richer than sun rays in visible light, and this would be contrary to (5). May it not be that while a large proportion of the particles of the inner corona is gaseous, a considerable proportion is liquid or solid? Then may not the light of the inner corona be mainly reflected, like that of the outer corona, but with the bright line spectrum of incandescent gases present in sufficient strength to nearly obliterate the dark Fraunhofer lines of the reflected sun rays? The continuous spectrum of the incandescent solid and liquid particles present would tend to increase the transmissibility of the coronal brightness to the asphaltum screen; so that the opposite tendency of the diffuse reflection of the gaseous particles present would be counteracted. At increasing distances from the limb we may suppose the particles would be cooler, and mainly solid or liquid, so that incandescence would wane and a dark line spectrum would gradually appear. Still, the transmissibility and color would remain nearly unchanged, because the light would be still mainly reflected sunlight, and the particles now so large as not to enrich the proportion of blue light, but rather slightly to decrease it.

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[1] Arrhenius computes a possible temperature of 4,620° at 0.7′ from the limb, and then suggests that the matter there may be liquid drops. How is this possible?

[2] The gaseous material of the sun itself is under enormous pressure, so that its spectrum is thereby made continuous. Not so the corona.

[3] Specification (4) is no obstacle, because the particles near the sun receive light from a solid angle of nearly a whole hemisphere, and would therefore show no polarization in any particular direction, because partially polarized in all.

As for the attractive hypothesis of electrical discharge luminescence, like that of the aurora, one hesitates to recommend recourse to a source so little known. So far as known, too, this hypothesis, like the others, has difficulty to reckon with the character of the photographic coronal spectrum.

The cause of the corona-brightness seems very difficult to decide, in view of conflicting considerations; but in the judgment of the writer the hypothesis that it is mainly due to the reflection of ordinary sun rays, but modified by radiation of incandescence and perhaps also luminescence, seems most tenable.

In conclusion, it is a pleasure to acknowledge the great aid afforded by the director and staff of the Lick Observatory Expedition; the conscientious and able work of my assistant, Mr. Moore; the intelligent and faithful assistance rendered on the day of the eclipse by Chief Yeoman Chase, of the *Annapolis;* the aid furnished by the owners and manager of Flint Island, and the uniformly cordial and courteous attentions of Governor Moore and the officers of the *Annapolis,* and of many others during the time when the expedition was in transit.