XIII. *Further Experiments on the Light of the Cassegrainian Telescope compared with that of the Gregorian. By Captain* Henry Kater, *Brigade Major. In a Letter addressed to the Right Hon. Sir* Joseph Banks, *Bart. K. B. P. R. S.*

Read November 18, 1813.

Sir,

Since you did me the honour of submitting to the Royal Society my experiments on the comparative light of the Cassegrainian and Gregorian telescopes, I have been so fortunate as to have an opportunity of establishing the conclusions deduced from them by another experiment, the detail of which I trust will not prove unacceptable.

The telescopes used on the present occasion were the excellent Gregorian described in my former paper, and a new Cassegrainian constructed by Mr. Crickmore. The diameter of the large speculum of this instrument is 4,9 inches, the distance between the mirrors only 18 inches, and it bears a power of about 550 (as roughly determined by experiment) with perfect distinctness and considerable light.

The magnifying powers used were 157 in the Cassegrainian, and 125 in the Gregorian; these were carefully determined by experiment. A circular piece of pasteboard was then prepared to close the end of the Cassegrainian telescope, and concentric circles were drawn on it at the distance of the twentieth of an inch from each other. These were succes-

sively cut out till a card appeared decidedly brighter when viewed through the Cassegrainian than through the Gregorian.

The following measures were then taken.

Cassegrainian Telescope.	Inch.	Gregorian Telescope.	Inch.
Diameter of the circular opening in the pasteboard - -	3,600	Diameter of the large mirror -	3,950
Diameter of the back of the small mirror	1,900	Diameter of the back of the small mirror	1,230
Length of the arm	0,850	Length of the arm	1,155
Thickness of ditto	0,225	Thickness of ditto	0,175
		Length of a bar containing the adjustment	0,700
		Its width -	0,150
		Diameter of three semicircles used as rests for the great mirror	0,375

From the above data the following calculations were made.

	Inch.		Inch.
Area of the circular opening in the pasteboard -	10,179	Area of the large mirror - -	12,254
Area of the back of the small mirror to be deducted -	2,836	Area of the back of the small mirror to be deducted -	1,188
Area of the arm to be deducted	0,191	Area of the arm to be deducted	0,202
	3,027	Area of the bar containing the adjustment to be deducted	0,105
		Area of the three semicircles to be deducted	0,166
			1,661
Area of the portion of the mirror exposed to the light -	7,152	Area of the portion of the mirror exposed to the light -	10,593

The magnifying powers being 157 in the Cassegrainian telescope and 125 in the Gregorian, their comparative light when reduced to the same aperture and power will be as $\frac{10,593}{125^2}$ to $\frac{7,152}{157^2}$, or as 678 to 290.

It may perhaps be desirable to place the results of the three experiments in one point of view. Thus, calling the light of the Gregorian telescope in every instance 100, we have the light of a telescope of the Cassegrainian form of equal power and aperture, by the first experiment 235, by the second 148, and by the third 234.

The surprising agreement of the first and third experiments with each other, excites an inquiry as to the cause of the difference observable in the second, as equal care and attention were bestowed on all.

The Cassegrainian telescope used on that occasion I have been unable to procure again, but from the inquiries I have since made, there is some reason to believe that, in addition to the polish of the specula having been somewhat impaired, as remarked in my last paper, its convex mirror was too small to receive the whole cone of rays, and to this circumstance principally I am inclined to attribute the deficiency of light in the second experiment when compared with the first and third.

If the mean of all three experiments be taken, the relative quantity of light will be as $20\frac{1}{2}$ to 10; but, if the second experiment be rejected, and the mean of the first and third be considered as correct, the light will be very nearly as $23\frac{1}{2}$ to 10 in favour of a telescope of the Cassegrainian form compared with one of the Gregorian construction.

I have the honour to remain, &c. &c.

Ipswich, 16th July, 1813. HENRY KATER.

P. S. A fact which appears to be somewhat analogous to that which I have observed, has been remarked by Dr. BREWSTER *in his late treatise* on Philosophical Instruments. "It is a curious fact," he says, p. 44, "that the circular images or the sections of the cone of rays, are never so distinct and well defined after the rays have crossed—as they are before—;" and again, p. 193, "the sections of the cones of light are, in general, better defined, when they are taken between the object glass and its principal focus."

APPENDIX.

SINCE the preceding paper was submitted to the Royal Society, I have made numerous experiments connected with the same subject for the purpose of bringing the results I then deduced to the test of a further examination, conducted in a different manner, and with a more simple apparatus.

My object was to determine the intensity of light reflected from a concave mirror at equal distances from its focus, and thus to decide, in a direct manner, whether any rays are lost in crossing each other at the place where an image is formed.

The mirror employed in these experiments belongs to an excellent Newtonian telescope; its diameter is 4,6, and its solar focus 22,5 inches. This mirror was supported by means of a cylindrical rod of iron screwed to the back of the cell which contains it, on two upright pieces of wood mortised into a square board, which thus formed a frame in which the mirror might be fixed in any required position.

The mirror being placed to receive the rays of the sun, I held a card at such a distance within the focus, that the luminous circle formed by reflection was equal in diameter to the width of the card; and having endeavoured to fix in my mind the degree of illumination, I suddenly removed the card far beyond the focus, and then brought it towards the mirror till the diameter of the luminous circle was the same as before. In this position the degree of illumination appeared so far inferior to that before observed, as to admit of no hesitation in the decision.

Before I proceed to detail the experiments which follow, I must premise that of the eight persons who at different times were employed in making the observations, six were perfectly unacquainted with the subject of inquiry, and two of the six distinguished in the column of observers by the letters C, and W, were servants. It will be seen, that I did not trust myself to make any observations till the fact I sought had been sufficiently established by others to leave no fear on my mind that I might be influenced by any preconceived opinion.

I drew a line across a card, which line I divided into tenths of an inch. The mirror was placed at the distance of fourteen feet from a candle, and the card moved in the reflected light *within* the focus till the diameter of the luminous circle was equal to the width of the card, in which position an observer was directed to remark carefully the intensity of the illumination. The card was then suddenly carried far *beyond* the focus and brought slowly towards it till the observer pronounced the intensity of the light to be the same as before, at which instant I noted the diameter of the luminous circle by means of the divided line drawn on the card: the square of this

diameter compared with the square of the diameter of the first circle, gave the ratio of the intensity of light at equal distances from the focus.

Observers.	Diameter of the illuminated circle *within* the focus.	Diameter of the circle of equal illumination *without* the focus.	Ratio of the intensity of the light at equal distances from the focus.	
			Within.	Without.
A	24	17	1000	502
B	25	17	1000	445
K	25	17	1000	445
C	25	18	1000	518
		Mean	1000	477,5

I now caused a joint to be made in front of the board supporting the mirror, which received the end of a light rod of wood about three feet in length. On this a thin board was contrived to slide easily at right angles, and the rod moving stiffly in the joint, could be set to any elevation so as to receive the light reflected from the mirror on the thin board. The board was covered with white paper divided by perpendicular lines at the distance of the tenth of an inch from each other. The observations were then made, and the ratio of the light deduced in the same manner as in the preceding experiments.

Observers.	Diameter of the illuminated circle *within* the focus.	Diameter of the circle of equal illumination *without* the focus.	Ratio of the intensity of the light at equal distances from the focus.	
			Within.	Without.
Y	24,3	15,75	1000	420
Y	24,3	16,00	1000	433
K	24,3	14,50	1000	352
K	24,3	16,25	1000	447
K	24,3	16,25	1000	447
M	24,3	16,00	1000	433
M	24,3	16,50	1000	461
M	24,3	15,00	1000	381
		Mean	1000	421,6

Not being perfectly satisfied with the manner in which these experiments were conducted, I was anxious to devise some means of viewing the light on both sides of the focus at the same time; and this to a certain degree I accomplished in the following manner.

I caused two small blocks of wood to be made to slide easily on the rod beforementioned, and cut in each a notch with a fine saw to receive a slip of card at right angles to the rod. On each card a circle of half an inch in diameter was drawn which remained white, the rest of the card being painted black. By this contrivance, I could receive on each circle a portion of the light reflected from the mirror when the slips of card were placed one within the focus, and the other without. The one without the focus remained stationary, whilst that within was shifted till the observer pronounced the white circles to be equally illuminated, when the distance between the cards was

carefully measured. At the conclusion of these observations, the card next the mirror was moved till a perfect image of the candle was formed on it, when its distance from the card beyond the focus was measured, and the mean of a number of these last observations (differing but little from each other) was taken, in order to ensure a more accurate result. The distance of each card from the focus when the light was of equal intensity being thus obtained, the squares of those distances will express the relative intensity of illumination at equal distances on either side of the focus.

With white circles on black cards.

Observers.	Distance of the white circles when equally illuminated.	Distance of the white circle from the focus *without*.	Distance of the white circle from the focus *within*.	Ratio of the intensity of the light at equal distances from the focus.	
				Within.	Without.
Myself	25,25	10,	15,25	1000	430
——	25,75	10,	15,75	1000	403
——	25,30	10,	15,30	1000	427
K	25,13	10,	15,13	1000	437
——	26,25	10,	16,25	1000	379
——	25,25	10,	15,25	1000	430
C	24,25	10,	14,25	1000	492
——	25,37	10,	15,37	1000	423
——	24,75	10,	14,75	1000	460
			Mean	1000	431,2

Conceiving that some error might possibly arise from the one circle being nearer to the eye than the other, I substituted for them transparent disks of six-tenths of an inch diameter,

made by cutting circular holes in two slips of black card paper, and covering them with fine oiled paper. Small shades of black card paper were contrived to shield the disks from the direct rays of the candle. The disk within the focus being made the brightest, was moved at intervals towards the mirror till the observer pronounced both disks to be equally illuminated, when their distance was registered as the "*first reading*." The disk within the focus was then advanced so near the mirror, as to appear much the faintest, and afterwards brought back gradually till the illumination of the disks was a second time pronounced to be equal, when their distance was again measured and entered under the head of "*second reading*," and the same method was followed in all the subsequent experiments.

With large transparent disks.
Distance of the candle from the mirror 186 inches.

Observers.	Distance of the disks when equally illuminated.		Distance of the disk from the focus *without*.	Distance of the disk from the focus *within*.	Ratio of the intensity of the light at equal distances from the focus.	
	1st reading.	2d reading.			Within.	Without.
Myself	26,45	25,70	10, 3	15,77	1000	427
K	24, 5	2 5. 6	10,22	14,83	1000	475
				Mean	1000	451

In making the third set of experiments I remarked that a part of the light from the mirror was received on that portion of the card which was blackened, and fearing that this circum-

stance by diverting the attention from the white circles might occasion an inaccurate decision, I prepared two white disks of card paper half an inch in diameter, which were supported on black wires, and these I found far preferable to every other contrivance which I employed. Care was taken to place the disks as near the axis of the mirror as was possible without their interfering with each other.

The following were the results.

With disks of card paper supported on wires.
Distance of the candle from the mirror 186 inches.

Observers	Distance of the disks when equally illuminated.			Distance of the disk from the focus *without*.	Distance of the disk from the focus *within*.	Ratio of the intensity of the light at equal distances from the focus.	
	1st reading.	2d reading.	Mean.			Within.	Without.
W	25,07	24,95	25,01	9,8	15,21	1000	415
K	23,90	24,85	24,37	9,8	14,57	1000	452
Myself	24,80	25,00	24,90	9,8	15,10	1000	421
K	23,40	24,95	24,17	9,8	14,37	1000	465
W	23,70	24,35	24,02	9,8	14,22	1000	475
Myself	23,82	24,60	24,21	9,8	14,41	1000	463
					Mean	1000	448,5

Imagining that the superior whiteness of plaister of Paris might render a slight difference of light more perceptible than it could be by the card disks, I prepared two balls of this substance by casting them in a bullet mould, and supported them on black wires. With these the following experiments were made.

With Plaister of Paris balls.

Distance of the candle from the mirror 186 inches.

Observers	Distance of the balls when equally illuminated.			Distance of the balls from the focus *without.*	Distance of the balls from the focus *within.*	Ratio of the intensity of the light at equal distances from the focus.	
	1st reading.	2d reading.	mean.			Within.	Without.
W	24,20	24,43	24,31	10,	14,31	1000	488
K	25,50	24,8	25,15	10,	15,15	1000	436
Myself	25,40	25,67	25,53	10,	15,53	1000	415
W	24,77	25,60	25,18	10,	15,18	1000	434
K	24,77	24,15	24,46	10,	14,46	1000	478
Myself	24,85	24,77	24,81	10,	14,81	1000	456
					Mean	1000	451,1

Lastly, having made only two experiments with transparent disks, and those being of an inconvenient size, I prepared others four-tenths of an inch in diameter, which were constructed and used as before.

With small Transparent Disks.

Distance of the candle from the mirror 186 inches.

Observers	Distance of the disks when equally illuminated.			Distance of the disk from the focus *without.*	Distance of the disk from the focus *within.*	Ratio of the intensity of the light at equal distances from the focus.	
	1st reading.	2d reading.	mean.			Within.	Without.
W	23,85	26,50	25,17	10,26	14,91	1000	474
K	25,20	25,65	25,42	10,26	15,16	1000	458
Myself	25,37	25,43	25,40	10,26	15,14	1000	459
					Mean	1000	463,7

If the mean results of the various experiments be now collected they will appear as follows:

1st set.	By the diameters of the circles of illumination - - -	1000	477,5
2d —	By ditto - - -	1000	421,6
3d —	By white circles on black cards	1000	431,2
4th —	By large transparent disks -	1000	451,0
5th —	By disks of card paper on wires	1000	448,5
6th —	By Plaister of Paris balls -	1000	451,1
7th —	By small transparent disks -	1000	463,7
	Mean	1000	449,2

The following method, by which both disks may be seen at the same instant, was suggested by a friend.

Two lamps were procured, and the wicks being trimmed so that the flames appeared of an equal size, one lamp was placed 16 feet from the mirror, and the other 4 feet, which

last distance, as will be seen, was varied in the course of the experiments. Two small disks of card paper a quarter of an inch in diameter, supported on wires, were fixed on one of the sliders, one inch and three quarters from each other, and both at the same distance from the mirror. The slider being placed between the two foci of the lamps, they were arranged so that the reflected light from the most distant lamp fell on one of the disks *after* the rays had crossed at the focus, and that from the nearest lamp was received by the other disk *before* the rays arrived at the focus. The slider was then moved between the foci till the disks appeared equally illuminated, when the division (the rod being divided into inches and tenths) cut by the slider was registered. The slider was then moved till a well defined image of the furthest lamp appeared on the disk, and the division cut by the slider being noted, the distance of the disks, when equally illuminated, from the focus of the furthest lamp was readily obtained. The foci of the two lamps being calculated, their difference was known, and by means of it, and the distance of the disks from the focus of the furthest lamp, their distance from the focus of the *nearest* lamp was determined. The mean of several readings was in every instance taken to insure a more accurate result, and the lamps were changed during each experiment, in order to obviate any error which might arise from the inequality of their light. The rays from the distant lamp were first thrown on the right hand disk, and in the subsequent series on the left; by which the error arising from any shade of difference in the disks (if such existed) was corrected.

Let L, be the distance of the furthest lamp.

l, That of the nearest.

f, *The focus of the furthest* lamp.

F, The focus of the nearest lamp.

d, The distance of the disks from the focus of the *furthest* lamp when equally illuminated.

D, The distance of the disks from the focus of the *nearest* lamp when equally illuminated.

Then the relative intensity of the light at *equal* distances on each side of the focus will be $\left(\frac{f}{L \times d}\right)^2 : \left(\frac{F}{l \times D}\right)^2$.

With disks of card paper. Distance of the furthest lamp 16 feet.

Rays from the furthest lamp on the right hand disk.				Rays from the furthest lamp on the left hand disk.		
Distance of the nearest lamp	Distance of disks from the focus when equally illuminated.		Intensity of light without the focus, that within being 1000.	Distance of disks from the focus when equally illuminated.		Intensity of light without the focus, that within being 1000.
	Without.	Within.		Without.	Within.	
5	1 74	8,77	804	1,75	8,76	815
6	1,47	5,76	763	1,57	5,66	901
7	1,14	4,10	587	1,32	3,92	857

The mean of these experiments gives the intensity of light within the focus to that without, as 1000 : 788.

Disks of glass ground on both sides were now substituted for those of card paper, and with these the following experiments were made with the utmost care.

With disks of ground glass. Distance of the furthest lamp 16 feet.

Rays from the furthest lamp on the right hand disk.				Rays from the furthest lamp on the left hand disk.		
Distance of the nearest lamp.	Distance of disks from the focus when equally illuminated.		Intensity of light *without* the focus, that within being 1000.	Distance of disks from the focus when equally illuminated.		Intensity of light without the focus, that within being 1000.
	Without.	Within.		Without.	Within.	
4	2,58	14,28	1441	1,71	15,15	563
5	1,80	8,71	872	1,52	8,99	584
6	1,36	5,87	629	1,34	5 89	606
7	1,16	4 08	614	1,17	4,07	627

From these experiments, the intensity of light within the focus to that without appears to be, as 1000 : 742; but as the first experiment is evidently erroneous, if it be rejected, the intensity of the light within the focus to that without, will be as 1000 : 655.

The difference of these results from those obtained by the methods detailed in the former part of this paper, led me to examine the intensity of the light of both cones of rays *within* the foci. For this purpose, the following experiments were made.

With disks of ground glass *within the foci*.
Distance of the furthest lamp 16 feet.

Rays from the furthest lamp on the right hand disk.				Rays from the furthest lamp on the left hand disk.			
Distance of the nearest lamp.	Distance of the disks when equally illuminated from the focus of the furthest lamp.	Distance of the disks when equally illuminated from the focus of the nearest lamp.	Intensity of the light within the focus of the furthest lamp, that within the focus of the nearest being 1000.	Distance of the disks when equally illuminated from the focus of the furthest lamp.	Distance of the disks when equally illuminated from the focus of the nearest lamp.	Intensity of the light within the focus of the furthest lamp, that within the focus of the nearest being 1000.	Mean.
4	3,38	20,24	1231	3,14	20,00	1089	1160
5	3,22	13,73	1124	3,23	13,74	1129	1126
6	3,30	10,53	1151	3,16	10,39	1084	1117
7	3,26	8,50	1117	3,12	8,36	1058	1087
8	3,19	6,99	1108	2,98	6,88	998	1053

From these last experiments, it should seem that a portion of the light forming the cone of rays from the nearest lamp is destroyed by the interference of the cone of rays from the furthest lamp; but this is an inference too improbable to be received as conclusive without further experiments.

The preceding method of determining the proportional intensity of light without the focus to that within, is not much to be relied upon, from the circumstance of the light after it has crossed at the focus appearing of a *deeper yellow colour* than before, which renders it extremely difficult to decide when the disks are equally illuminated; the circle of light, too, from the furthest lamp being very small so near the focus, and its illumination unequal in different parts, forms another source

of error; from these objections, however, I must observe, the experiments made within both foci are in a great measure exempt.

With respect to the experiments detailed in the preceding part of this paper, it may be remarked in their favour, that the observations were made by eight different persons at various times, and by different methods, and that the near coincidence of the results with each other, and with the numbers deduced from the experiments made with the Cassegrainian and Gregorian telescopes, seem to warrant the conclusion that a mean of the whole may be considered as a tolerable approximation to the truth.

London, April 20, 1814.