PHILOSOPHICAL

TRANSACTIONS.

XII. *Observations of a Comet, made with a View to investigate its Magnitude and the Nature of its Illumination. To which is added, an Account of a new Irregularity lately perceived in the apparent Figure of the Planet Saturn.* *By* William Herschel, *LL. D. F. R. S.*

Read April 7, 1808.

THE comet which we have lately observed, was pointed out to me by Mr. PIGOTT, who discovered it at Bath the 28th of September, and the first time I had an opportunity of examining it was the 4th of October, when its brightness to the naked eye gave me great hopes to find it of a different construction from many I have seen before, in which no solid body could be discovered with any of my telescopes.

In the following observations, my attention has been directed to such phenomena only, as were likely to give us some information relating to the physical condition of the comet, it will therefore not be expected that I should give an account of its motion, which I was well assured would be

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most accurately ascertained at the Royal Observatory at Greenwich.

The different parts of a comet have been generally expressed by terms that may be liable to misapprehension, such as the head, the tail, the coma, and the nucleus; for in reading what some authors say of the head, when they speak of the size of the comet, it is evident that they take it for what is often called the nucleus. The truth is, that inferior telescopes, which cannot show the real nucleus, will give a certain magnitude of the comet, which may be called its head; it includes all the very bright surrounding light; nor is the name of the head badly applied, if we keep it to this meaning; and since, with proper restriction, the terms which have been used may be retained, I shall give a short account of my observations of the comet, as they relate to the above-mentioned particulars, namely, the nucleus, the head, the coma, and the tail, without regarding the order of the time when they were made; the date of each observation, however, will be added, that any person who may hereafter be in possession of more accurate elements of the comet's orbit, than those which I have at present, may repeat the calculations in order to obtain a more correct result.

Of the Nucleus.

From what has already been said, it will easily be understood that by the nucleus of the comet, I mean that part of the head which appears to be a condensed or solid body, and in which none of the very bright coma is included. It should be remarked, that from this definition it follows, that when the nucleus is very small, no telescope, but what has light and power in an eminent degree, will show it distinctly.

Observations.

Oct. 4, 1807. 10-feet reflector. The comet has a nucleus, the disk of which is plainly to be seen.

Oct. 6. I examined the disk of the comet with a proper set of diaphragms, such as described in a former paper,* in order to see whether any part of it were spurious; but when the exterior light was excluded, so far from appearing larger, as would have been the case with a spurious disk, it appeared rather diminished for want of light; nor was its diameter lessened when I used only the outside rays of the mirror. The visible disk of the comet therefore is a real one.

Oct. 4. I viewed the comet with different magnifying powers, but found that its light was not sufficiently intense to bear very high ones. As far as 200 and 300, my 10-feet reflector acted very well, but with 400 and 500 there was nothing gained, because the exertion of a power depending on the quantity of light was obstructed,† which I found was here of greater consequence than the increase of magnitude.

Illumination of the Nucleus.

Oct. 4, 6^h 15′. The nucleus is apparently round, and equally bright all over its disk. I attended particularly to its roundness.

Oct. 18. The nucleus is not only round, but also every where of equal brightness.

Oct. 19. I see the nucleus again, perfectly round, well defined, and equally luminous. Its brilliant colour in my 10-feet

* See Phil. Trans. for 1805, page 53. Use of the Criterion.

† See Phil. Trans. for 1800, p. 78.

telescope is a little tinged with red; but less so than that of Arcturus to the naked eye

Magnitude of the Nucleus.

Oct. 26. In order to see the nucleus as small as it really is, we should look at it a long while, that the eye may gradually lose the impression of the bright coma which surrounds it. This impression will diminish gradually, and when the the eye has got the better of it, the nucleus will then be seen most distinctly, and of a determined magnitude.

Oct. 4. With a 7-feet reflector I estimated the diameter of the nucleus of the comet at first to be about five seconds, but soon after I called it four, and by looking at it longer, I supposed it could not exceed three seconds.

Oct. 6. 10-feet reflector, power 221. The apparent disk of the comet is much less than that of the GEORGIAN planet, which being an object I have seen so often with the same instrument and magnifying power, this estimation from memory cannot be very erroneous.

Oct. 5. Micrometers for measuring very small diameters, when high magnifying powers cannot be used, being very little to be depended upon, I erected a set of sealing wax globules upon a post at 2422 inches from the object mirror of my 10-feet reflector, and viewed them with an eye-glass, which gives the instrument a power of 221, this being the same which I had found last night to show the nucleus of the comet well. I kept them in their place all the day, and reviewed them from time to time, that their magnitudes might be more precisely remembered in the evening, when I intended to compare the appearance of the nucleus with them.

On examining the comet, I found the diameter of its nucleus to be certainly less than the largest of my globules, which being ,0466 inch, subtended an angle of 3″,97 at the distance of the telescope in the day time.

Comparing the nucleus also with the impressions, which the view of the second and third had left in my memory, and of which the real diameters were ,0325 and ,0290 inch; and magnitudes at the station of the mirror 2″,77 and 2″,47, I found that the comet was almost as large as the second, and a little larger than the third.

Oct. 18. The nucleus is less than the globule which subtends 2″,77.

Oct. 19. The air being uncommonly clear, I saw the comet at 40 minutes after five, and being now at a considerable altitude, I examined it with 289, and having but very lately reviewed my globules, I judged its diameter to be not only less than my second globule, but also less than the third; that is, less than 2″,47.

Oct. 6. The 20-feet reflector, notwithstanding its great light, does not show the nucleus of the comet larger than the 10-feet, with an equal magnifier, makes it.

Oct. 28. My large 10-feet telescope, with the mirror of 24 inches in diameter, does not increase the size of the nucleus.

Oct. 6. Being fully aware of the objections that may be made against the method of comparing the magnitude of the nucleus of the comet with objects that cannot be seen together, I had recourse to the satellites of Jupiter for a more decisive result, and with my 7-feet telescope, power 202, I viewed the disk of the third satellite and of the nucleus of the comet alternately. They were both already too low to be seen

very distinctly; the diameter of the nucleus however appeared to be less than twice that of the satellite.

Oct. 18. With the 10-feet reflector, and the power 221, a similar estimation was made; but the light of the moon would not permit a fair comparison.

Oct. 19. I had prepared a new 10-feet mirror, the delicate polish of my former one having suffered a little from being exposed to damp air in noctural observations. This new one being uncommonly distinct, and the air also remarkably clear, I turned the telescope from the comet to Jupiter's third satellite, and saw its diameter very distinctly larger than the nucleus of the comet. I turned the telescope again to the comet, and as soon as I saw it distinctly round and well defined, I was assured that its diameter was less than that of the satellite.

6^h 20′. I repeated these alternate observations, and always found the same result. The night is beautifully clear, and the moon is not yet risen to interfere with the light of the comet.

Nov. 20. With a 7-feet reflector, and power only 75, I can also see the nucleus; it is extremely small, being little more than a mere point.

Of the Head of the Comet.

When the comet is viewed with an inferior telescope, or if the magnifying power, with a pretty good one, is either much too low, or much too high, the very bright rays immediately contiguous to the nucleus will seem to belong to it, and form what may be called the head.

Oct. 19. I examined the head of the comet with an indifferent telescope, in the manner I have described, and found it

apparently of the size of the planet Jupiter, when it is viewed with the same telescope and magnifying power.

With a good telescope, I saw in the centre of the head a very small well defined round point.

Nov. 20. The head of the comet is now less brilliant than it has been.

Of the Coma of the Comet.

The coma is the nebulous appearance surrounding the head.

Oct. 19. By the field of view of my reflector, I estimate the coma of this comet to be about 6 minutes in diameter.

Dec. 6. The extent of the coma, with a mirror of 24 inches diameter, is now about $4' 45''$.

Of the Tail of the Comet.

Oct. 18. 7^h. With a night glass, which has a field of view of nearly $5°$, I estimated the length of the tail to be $3°\frac{3}{4}$; but twilight is still very strong, which may prevent my seeing the whole of it.

Nov. 20. The tail of the comet is still of a considerable length, certainly not less than $2\frac{1}{2}$ degrees.

Oct. 26. The tail of the comet is considerably longer on the south-preceding, than on the north-following side.

It is not bifid, as I have seen the comet of 1769 delineated, by a gentleman who carefully observed it.*

Oct. 28. 7-feet reflector. The south-preceding side of the tail in all its length, except towards the end, is very well defined; but the north-following side is every where hazy

* Dr. Lind of Windsor.

and irregular, especially towards the end; it is also shorter than the south-preceding one.

The shape of the unequal length of the sides of the tail, when attentively viewed, is visible in a night glass, and even to the naked eye.

Oct. 31. 10-feet reflector. The tail continues to be better defined on the south-preceding than on the north-following side.

Dec. 6. The length of the tail is now reduced to about 23′ of a degree.

Of the Density of the Coma and Tail of the Comet.

Many authors have said, that the tails of comets are of so rare a texture, as not to affect the light of the smallest stars that are seen through them. Unwilling to take any thing upon trust that may be brought to the test of observation, I took notice of many small stars that were occasionally covered by the coma and the tail, and the result is as follows.

Oct. 26, 6^h 15′. Large 10-feet reflector, 24 inches aperture. A small star within the coma is equally faint with two other stars that are on the north-following side of the comet, but without the coma.

7^h 30′. The coma being partly removed from the star, it is now brighter than it was before.

Oct. 31, 6^h 5′. 10-feet reflector. A star in the tail of the comet, which we will call *a*, is much less bright than two others, *b* and *c*, without the tail.

Two other stars, *d* and *e*, towards the south of *b* and *c*, are in the following skirts of the tail, and are extremely faint.

7^h 20′. The star *c* is now considerably bright, the tail having

left it, while *d*, which is rather more involved than it was before, is hardly to be seen.

7^h 50′. The star *a*, towards which the comet moves, is involved in denser nebulosity than before, and is grown fainter.

d is involved in brighter nebulosity than before, but being near the margin, it will soon emerge,

8^h 35′. Being still more involved, the star *a* is now hardly visible.

e is quite clear of the tail, and is a considerable star; *d* remains involved.

9^h 10′. The star *d* is also emerged, but the comet is now too low to estimate the brightness of stars properly.

Nov. 25, 7^h 35′. There is a star *a* within the light of the tail, near the head of the comet, equal to a star *b* situated without the tail, but near enough to be seen in the field of view with *a*. The path of the head of the comet leads towards *a*, and a more intense brightness will come upon it.

8^h 46′ The star *a* is now involved in the brightness near the head of the comet, and is no longer visible, except now and then very faintly, by occasional imperfect glimpses; but the star *b* retains its former light.

Nebulous appearance of the Comet.

Dec. 6. The head of the comet, viewed with a mirror of 24 inches diameter, resembles now one of those nebulæ which in my catalogues would have been described, "a very large, brilliant, round nebula, suddenly much brighter in the middle."

Dec. 16. 7-feet reflector. The night being fine, and the moon not risen, the comet resembles "a very bright, large,

irregular, round nebula, very gradually much brighter in the middle, with a faint nebulosity on the south preceding side."

Jan. 1. 1808. 7-feet. "Very bright, very large, very gradually much brighter in the middle."

If I had not known this to be a comet, I should have added to my description of it as a nebula, that the center of it might consist of very small stars, but this being impossible, I directed my 10-feet telescope with a high power to the comet, in order to ascertain the cause of this appearance; in consequence of which I perceived several small stars shining through the nebulosity of the coma.

Jan. 14. 7-feet. "Bright, pretty large, irregular round, brighter in the middle."

Feb. 2. 10-feet, 24-inch aperture. "Very bright, large, irregular round, very gradually much brighter in the middle." There is a very faint diffused nebulosity on the north-preceding side; I take it to be the vanishing remains of the comet's tail.

Feb 19. Considerably bright; about $\frac{1}{7}$ of the field $= 3' 26''$ "in diameter, gradually brighter in the middle." The faint nebulosity in the place where the tail used to be, still projects a little farther from the center than in other directions.

Feb. 21. Less bright than on the 19th; nearly of the same size; gradually brighter in the middle. The nebulosity still a little projecting on the side where the tail used to be.

Result of the foregoing Observations.

From the observations which are now before us, we may draw some inferences, which will be of considerable importance with regard to the information they give us, not only of

the size of the comet, but also of the nature of its illumination.

A visible, round and well defined disk, shining in every part of it with equal brightness, elucidates two material circumstances; for since the nucleus of this comet, like the body of a planet, appeared in the shape of a disk, which was experimentally found to be a real one, we have good reason to believe that it consists of some condensed or solid body, the magnitude of which may be ascertained by calculation. For instance, we have seen that its apparent diameter, the 19th of October, at 6^h 20′, was not quite so large as that of the 3d satellite of Jupiter. In order therefore to have some idea of the real magnitude of our comet, we may admit that its diameter at the time of observation was about 1″, which certainly cannot be far from truth. The diameter of the 3d satellite of Jupiter, however, is known to have a permanent disk, such as may at any convenient time be measured with all the accuracy that can be used; and when the result of such a measure has given us the diameter of this satellite, it may by calculation be brought to the distance from the earth at which, in my observation, it was compared with the diameter of the comet, and thus more accuracy, if it should be required, may be obtained. The following result of my calculation however appears to me quite sufficient for the purpose of a general information. From the perihelion distance 0,647491, and the rest of the given elements of the comet, we find that its distance from the ascending node on its orbit at the time of observation was 73° 45′ 44″; and having also the earth's distance from the same node, and the inclination of the comet's orbit, we compute by these data the angle at the sun. Then

by calculating in the next place the radius vector of the comet, and having likewise the distance of the earth from the sun, we find by computation that the distance of the comet from the earth at the time of observation was 1,169192, the mean distance of the earth being 1. Now since the disk of the comet was observed to subtend an angle of 1″, which brought to the mean distance of the earth gives 1″,169, and since we also know that the earth's diameter, which, according to Mr. DALBY, is 7913,2 miles,* subtends at the same distance an angle of 17″,2 we deduce from these principles the real diameter of the comet, which is 538 miles.

Having thus investigated the magnitude of our comet, we may in the next place also apply calculation to its illumination. The observations relating to the light of the comet were made, from the 4th of October to the 19th. In all which time the comet uniformly preserved the appearance of a planetary disk fully enlightened by the sun: it was every where equally bright, round, and well defined on its borders. Now as that part of the disk which was then visible to us, could not possibly have a full illumination from the sun, I have calculated the phases of the comet for the 4th and for the 19th, the result of which is, that on the 4th the illumination was 119° 45′ 9″ as represented in figure 1, and that on the 19th it had gradually increased to 124° 22′ 40″, of which a representation is given in figure 2. Both phases appear to me sufficiently defalcated, to prove that the comet did not shine by light reflected from the sun only; for had this been

* See Phil. Trans. for 1791, page 239, Mr. DALBY gives the two semi-axes of the earth, from a mean of which the above diameter 7913,1682 is obtained.

the case, the deficiency I think would have been perceived, notwithstanding the smallness of the object. Those who are acquainted with my experiments on small silver globules,* will easily admit, that the same telescope, which could shew the spherical form of balls, which subtended only a few tenths of a second in diameter, would surely not have represented a cometary disk as circular, if it had been as deficient as are the figures which give the calculated appearances.

If these remarks are well founded, we are authorised to conclude, that the body of the comet on its surface is self-luminous, from whatever cause this quality may be derived. The vivacity of the light of the comet also, had a much greater resemblance to the radiance of the stars, than to the mild reflection of the sun's beams from the moon, which is an additional support of our former inference.

The changes in the brightness of the small stars, when they are successively immerged in the tail or coma of the comet, or cleared from them, prove evidently, that they are sufficiently dense to obstruct the free passage of star-light. Indeed if the tail or coma were composed of particles that reflect the light of the sun, to make them visible we ought rather to expect, that the number of solid reflecting particles, required for this purpose, would entirely prevent our seeing any stars through them. But the brightness of the head, coma, and tail alone, will sufficiently account for the observed changes, if we admit that they shine not by reflection, but by their own radiance; for a faint object projected on a bright ground, or seen through it, will certainly appear somewhat fainter, although its rays should meet with no obstruction in coming to

* See Phil. Trans. for 1805, page 38, the 5th experiment.

the eye. Now, as in this case, we are sure of the bright interposition of the parts of the comet, but have no knowledge of floating particles, we ought certainly, not to ascribe an effect to an hypothetical cause, when the existence of one, quite sufficient to explain the phenomena, is evident.

If we admit that the observed full illumination of the disk of the comet cannot be accounted for from reflection, we may draw the same conclusion, with respect to the brightness of the head, coma, and tail, from the following consideration. The observation of the 2d of February mentions that not only the head and coma were still very bright, but that also the faint remains of the tail were still visible; but the distance of the comet from the earth, at the time of observation, was nearly 240 millions of miles,* which proves, I think, that no light reflected from floating particles could possibly have reached the eye, without supposing the number, extent, and density of these particles, far greater than what can be admitted.

My last observation of the comet, on the 21st of February, gives additional support to what has been said; for at the time of this observation, the comet was almost 2,9 times the mean distance of the sun from the earth.† It was also nearly 2,7 from the the sun.‡ What chance then could rays going to the comet from the sun, at such a distance, have to be seen after reflection, by an eye placed at more than 275 millions of miles§ from the comet? And yet the instant the

* 239894939.

† The sun's mean distance being 1, that of the comet was 2,89797.

‡ The comet's distance from the sun was 2,68,3196.

§ 275077889.

comet made its appearance in the telescope, it struck the eye as a very conspicuous object.

The immense tails also of some comets that have been observed, and even that of the present one, whose tail, on the 18th of October, was expanded over a space of more than 9 million of miles,* may be accounted for more satisfactorily, by admitting them to consist of radiant matter, such as, for instance, the aurora borealis, than when we unnecessarily ascribe their light to a reflection of the sun's illumination thrown upon vapours supposed to arise from the body of the comet.

By the gradual increase of the distance of our comet, we have seen that it assumed the resemblance of a Nebula; and it is certain, that had I met with it in one of my sweeps of the zones of the heavens, as it appeared on either of the days between the 6th of December, and the 21st of February, it would have been put down in the list I have given of nebulæ. This remark cannot but raise a suspicion that some comets may have actually been seen under a nebulous form, and as such have been recorded in my catalogues; and were it not a task of many years labour, I should undertake a review of all my nebulæ, in order to see whether any of them were wanting, or had changed their place, which certainly would be an investigation that might lead to very interesting conclusions.

Account of a new irregularity lately perceived in the apparent Figure of the Planet Saturn.

THE singular figure of Saturn, of which I have given an account in two papers, has continued, for several reasons, to

* 9160542.

claim my attention. When I saw the uncommon flattening of the polar regions of this planet, in the 40-feet telescope, I ascribed it to the attractive matter in the ring,* and of its tendency to produce such an effect we can have no doubt; but as another circumstance, which was also noticed, namely, an apparent small flattening of the equatorial parts, cannot be explained on the same principles, I wished to ascertain what physical cause might be assigned for this effect, and with a view to an investigation of this point, I have continued my observations. The position of the ring, at the last appearance of the planet, however, proved to be quite unfavourable for the intended purpose; for the very parts, which I was desirous of inspecting, were covered by the passage of the ring over the disk of the planet in front, or were projected on the ring, where it passed behind the body.

In my attempts to pursue this object, I perceived a new irregularity in the Saturnian figure, which, I am perfectly assured, had no existence the last time I examined the planet, and the following observations contain an account of it.

Observations.

June 16, 1807. The two polar regions of Saturn are at present of a very different apparent shape. The northern regions, as in former observations are flattened; but the southern are more curved or bulged outwards.

I asked my son JOHN HERSCHEL, who after me looked at Saturn while I was writing down the above observation, if he perceived that there was a difference in the curvature of the north and south pole, and if he did, to mark on a slate how

* See Phil. Trans. for 1805, page 276.

it appeared to him. When I examined the slate, I found that he had exactly delineated the appearance I have described.

In a letter to a very intelligent astronomical friend,* who has one of my 7-feet reflectors, I requested the favour of him to examine both the polar regions of Saturn, and to let me know whether he could perceive any difference in the appearance of their curvature; in answer to which I received, the 23d of June, a letter inclosing a drawing, in which also the southern regions were marked as more protuberant, with a greater falling off close to the irregularity. My friend, with his usual precaution, called this an illusion; and it will be seen by and by, that we shall have no occasion to ascribe this irregularity to a real want of due proportion, or settled figure of the polar regions of Saturn.

June 22, 9^h 24′. I see the same curved appearance at the south pole of Saturn, which was observed the 16th.

June 24. The air is very clear, and all the most critical phenomena are very distinctly to be seen; the shadow of the ring towards the south upon the planet; the shadow of the body towards the north-following side upon the ring; the belts upon the body; the division of the two rings; and with the same distinctness, I also see the protuberance of the south pole.

My seeing this appearance, at present, is a proof that it is not a physical irregularity or distortion of only some particular spot on the polar regions; for, in that case, it could not have been seen this evening, as from the rotation of the planet on its axis, which is 10^h 16′, the space of the polar circle which is now exposed to our view, must have been very different from what I saw the 16th and 22d.

* Dr. Wilson of Hampstead, late Professor of Astronomy at Glasgow.

Many observations were made afterwards, which all confirm the reality of this appearance.

It is so natural for us to reflect upon the cause of a new phenomena, that I cannot forbear giving an opinion on this subject. To suppose a real change in the whole zone of the planet, cannot be probable; it seems therefore that this appearance must be, as my friend calls it, an illusion. But since the reality of this illusion, if I may use the expression, has been ascertained by observation, it is certain that there must be some extrinsic cause for its appearance; and also that the same cause must not act upon the northern hemisphere. Now the only difference in the circumstances under which the two polar regions of Saturn were seen in the foregoing observations is the situation of its ring, which passes before the planet at the south, but behind at the north. The rays of light therefore which come to the eye from the very small remaining southern zone of the saturnian globe, pass at no great distance by the edge of the ring, while those from the north traverse a space clear of every object that might disturb their course. If therefore we are in the right to ascribe the observed illusion to an approximate interposition of the ring, we have, in the case under consideration, only two known causes that can modify light so as to turn it out of its course, which are inflection and refraction. The insufficiency of the first to account for the lifting up of the protuberant small segment of the northern regions will not require a proof. The effects of refraction on the contrary are known to be very considerable. Let us therefore examine a few of the particulars of the case. The greatest elevation of the visible segment above the ring did not amount to more than one second and three or four

Fig. 1.

Oct.r 4.th

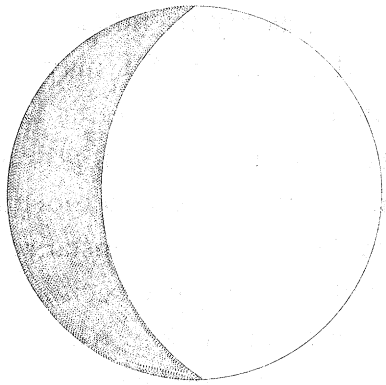
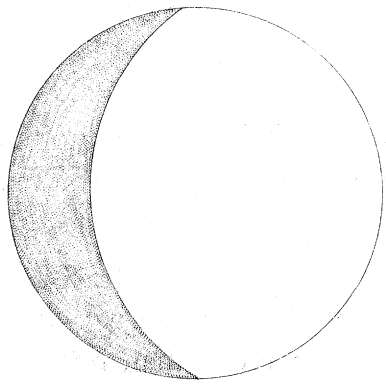


Fig. 2.

Oct.r 19.th



tenths. Then supposing the ring, the edge of which is probably of an elliptical figure, to have a surrounding atmosphere, it will most likely partake of the same form, and the rays which pass over its edge will undergo a double refraction: the first on their entrance into this atmosphere, and the second at their leaving it, and these refractions seem to be sufficient to produce the observed elevation. For should they raise the protuberant appearance only half a second, or even less, the segment could no longer range with the rest of the globe of Saturn, but must assume the appearance of a different curvature or bulge outwards.

The refractive power of an atmosphere of the ring has been mentioned in a former paper,* when the smallest satellites of Saturn were seen as it were bisected by the narrow luminous line under which form the ring appeared when the earth was nearly in the plane of it; and the phenomenon, of which the particulars have now been described, appears to be a second instance in support of the former.

* See Phil. Trans. for 1790, page 7.