XVII. *Further Observations on the Spectra of some of the Nebulæ, with a Mode of determining the Brightness of these Bodies.* *By* WILLIAM HUGGINS, *F.R.S.*

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§ I. *Introduction.*

IN my former papers, "On the Spectra of some of the Nebulæ" *, and "On the Spectrum of the Great Nebula in Orion" †, I described the results of a prismatic examination of the light of some of the objects in the heavens which have been classed together under the common denomination of Nebulæ. The present paper contains the results of the application of the same method of research, with the same apparatus, to the light of others of the same class of bodies. To these observations with the prism are appended the results of an attempt to determine the intrinsic intensity of the light emitted by some of the nebulæ which give a spectrum indicating gaseity.

On account of the great faintness of the light of most of the objects described in this paper, I have not found it possible to determine more than the general characters of the spectra which they form in the instrument. The present observations confirm the results which I have already presented to the Royal Society, namely, that with my instrument clusters and nebulæ give either a spectrum which is apparently continuous, or a spectrum consisting of one, two, or three bright lines.

The description "continuous spectrum" in this paper and in my former papers must not be understood to mean more than that when the slit was made as narrow as the feeble light of the object permitted, the spectrum was not resolved into bright lines. Whether the continuous spectrum was in any case interrupted by dark lines in a manner similar to the spectra of the sun and fixed stars, I was not able to ascertain; for when the feeble light of a nebula is dispersed by the prism into a spectrum consisting of light of all refrangibilities, the spectrum is extremely faint and difficult of examination. Before the slit is made sufficiently narrow for the detection of dark or bright lines, the spectrum becomes, in the case of nearly all the objects examined, too faint to be visible. When, however, a nebula is observed the light of which is monochromatic, or nearly so, the one, two, or three bright lines in which the light remains concentrated can usually be seen when the slit is made narrow. Some of these nebulæ have been examined with a slit not exceeding $\frac{1}{300}$ of an inch in width.

[A conclusion of some importance to our interpretation of the phenomena of these bodies, and especially of value in reference to the theoretical views we may form of the relation of the gaseous nebulæ to the other nebulæ and clusters, presents itself in con-

* Philosophical Transactions, 1864, p. 437. † Proceedings of the Royal Society, vol. xiv. p. 39.

nexion with these observations. The intensity of the brightest line of the gaseous nebulæ is in most cases greater than the intensity of the light of the *same refrangibility* of those nebulæ and clusters which furnish a spectrum which is apparently continuous. The superior intensity of the light may indicate a more intense heat. It may be therefore that of all the objects usually classed under the denomination of nebulæ and clusters, those which give a gaseous spectrum are, as a class, to be regarded as the *hottest*.—June 1866.]

The continuous spectra of some of the nebulæ and clusters are irregularly bright in some parts of the spectrum; but when the width of the slit was reduced, the bright portions did not appear to become more defined, as would be the case with a spectrum containing bright lines*. This irregularity of brightness may perhaps be due in some cases to the probable mode of formation of these continuous spectra. In the case, at least, of the clusters which the telescope resolves into stellar points, the spectrum must be composed of the blending together of the spectra of the constituent bright points. Now it is not improbable that these component spectra, like the spectra of the stars, differ from each other in the relative brightness of their different parts.

The positions in the spectrum of the bright lines of the gaseous nebulæ described in my former paper were determined by a simultaneous comparison in the instrument of these lines with the bright lines of nitrogen, hydrogen, and barium. The bright lines of the gaseous nebulæ referred to in this paper were not compared directly with any terrestrial spectra, partly because of the great faintness of most of these objects, and partly because the former comparisons were found to be injuriously fatiguing to the eye.

The value of this application of spectrum analysis appears to me to consist chiefly in the assistance which this method of observation may afford us in ascertaining the true nature of the nebulæ, and the relation which they sustain to the other orders of the heavenly bodies. I have therefore added to my prismatic observations such of the

* The peculiar appearance of the continuous spectra of some of the nebulæ and clusters has suggested to me, from my first examination of them, that possibly the luminous points into which the telescope resolves some of these objects may not be of the same nature as the true stars. My observations of the great nebula in Andromeda and of its small but bright companion in August 1864, were recorded thus:—"The spectrum appears to end abruptly in the orange; and throughout its length is not uniform, but is evidently crossed either by lines of absorption or by bright lines"[1]. [The same characters have since been found in several of the brighter nebulæ and clusters. It is possible to explain the absence of the less refrangible rays, which are wanting in these spectra, by supposing them to have been intercepted by absorbent vapours. The apparently *complete* want of light in this part of the spectrum, and the unequal, mottled appearance of the brighter parts of the spectrum, suggest rather that the light may have emanated from a gaseous source, and that the spectrum consists of numerous *bright* lines. The faintness of these spectra has prevented me from using a slit sufficiently narrow for the determination of their true nature. Some quite recent observations, which are not yet complete, appear to support the view that the bright points of some clusters may possess a physical constitution which is not analogous to that of the sun, and the brighter of the separate stars.—June 1866.]

[1] Philosophical Transactions, 1864, p. 442.

results of former telescopic observation as, in my opinion, would be of assistance to an understanding of the proper significance of the new information furnished by the prism.

[Although the detection in a nebula by the telescope of closely associated points of light can no longer be regarded as a trustworthy indication that the object consists of true stars, yet it is of importance to ascertain how far the classification of the nebulæ by the prism corresponds with the telescopic indications of their resolvability. I have Lord ROSSE'S permission to state that the matter of the Great Nebula in Orion, which the prism shows to be gaseous, has not been resolved by his telescope. In some parts of the nebula he observed a large number of exceedingly minute *red* stars. These red stars, however, though apparently connected with the irresolvable blue material of the nebula, yet seem to be distinct from it. The light of these stars is doubtless too feeble to furnish a visible spectrum.

Lord OXMANTOWN has examined all the observations made at Parsonstown of those nebulæ which I have subjected to prismatic examination. My list contained 41 nebulæ which give a continuous spectrum, and 19 gaseous nebulæ.

Lord OXMANTOWN finds that these nebulæ may be arranged thus:—

	Continuous spectrum.	Gaseous spectrum.
Clusters	10	0
Resolved, or resolved?.	5	0
Resolvable, or resolvable? . . .	10	6
Blue, or green, no resolvability . .	0	4
No resolvability seen	6	5
Total observed . .	31	15
Not observed . . .	10	4
	41	19—June 1866.]

The numbers and descriptions of the nebulæ, and their places for the epoch 1860.0, included within brackets, are taken from Sir JOHN F. W. HERSCHEL'S "General Catalogue of Nebulæ and Clusters of Stars"*.

§ II. *Observations of Nebulæ the Spectra of which indicate gaseity.*

[No. 2102. 3248 h. 27 H. IV. R.A. $10^h\,18^m\,2^s{\cdot}2$. N.P.D. 107° 55′ 50″. A planetary nebula. Very bright; little extended; position of longer dimension 135°; diameter $=32''\pm$; blue.]

This nebula was observed on April 25, 1865, with a silvered glass reflector. The spectrum consisted of one bright line about midway between *b* and F of the solar spectrum, and probably corresponding in position to the brightest of the lines of nitrogen.

In consequence of the imperfect adjustment, at this time, of the reflector, I was

* Philosophical Transactions, 1864, pp. 1–137.

unable to ascertain satisfactorily whether any other fainter lines were also present in the spectrum.

Sir JOHN HERSCHEL describes its appearance as "somewhat hazy, with a slight nebulous atmosphere"*.

D'ARREST'S measures of the diameter are—January 13, 1856, =25″, and March 11, 1856, =27″†.

[On March 14, 1866, I examined this nebula with my refractor of 8 inches aperture. Powers of 600 and 920 diameters showed that the nebula is annular. It appears to consist of an oval ring of brighter matter surrounded by a broad margin of faint nebulosity. The area enclosed by the ring, like that of the annular nebula in Lyra, is filled with faintly luminous matter. The faint nebulosity surrounding the ring appears circular, or nearly so, suggesting that the ring, seen obliquely from our system, exists within a globular mass of faint nebulous material.

When the spectroscope was applied, in addition to the bright line seen in 1865, the two other bright lines which are present in many nebulæ, were also observed. When the slit was made sufficiently narrow for these bright lines to appear defined, no trace of a continuous spectrum was detected. With a wide slit, however, I *suspected* a faint and broad continuous spectrum.—June 1866.]

[No. 4234. 1970 h. 5 Σ. R.A. $16^h\ 38^m\ 36^s$. N.P.D. 65° 56′ 10″. A planetary nebula; very bright; very small; disk and border.]

I observed this nebula, and all the objects which follow in this paper, with my refractor of 8 inches aperture.

On this nebula powers up to 1000 diameters were employed. With low powers this object appeared small, round, intensely bright, and decidedly blue in colour. Higher powers showed a uniform disk surrounded with a faint nebulous halo.

The prism resolves the light of this nebula into three bright lines, occupying the same positions in the spectrum as the bright lines of nebula No. 4373‡. The two brightest lines are bright, and differ not very greatly in intensity; the less refrangible of the lines is the brighter. The most refrangible of the three lines is much fainter than the others.

A very faint continuous spectrum was seen by glimpses.

Lord ROSSE describes this nebula:—"Intense blue centre fading off to some distance all around. I found once or twice there were projections. (N.B. The existence of these not satisfactorily proved"§.)

Sir JOHN HERSCHEL gives its diameter =8″‖.

D'ARREST'S measures of its diameter are—1856, March 12, =6″, June 1, =8″¶.

* Results of Astronomical Observations at the Cape of Good Hope, p. 94, and pl. 6, fig. 5.

† Resultate aus Beobachtungen der Nebelflecken und Sternhaufen, p. 326.

‡ Philosophical Transactions, 1864, p. 438. § Ibid. 1861, p. 732. ‖ Ibid. 1833, p. 458.

¶ Beobachtungen der Nebelflecken und Sternhaufen, p. 341.

[No. 4403. 2008 h. 17 M. R.A. $18^h\ 12^m\ 33^s$. N.P.D. 106° 13′ 36″. Remarkable object. Bright; extremely large; extremely irregular figure; 2-hooked.]

Sir JOHN HERSCHEL observes of this nebula, "A most curious object, not unlike the nebula of Orion (as it used to be figured like a Greek capital omega, Ω). There is in it a resolvable portion * or knot distinctly separated from and insulated in the rest, as if it had absorbed the nebula near it. Its form is like the Greek Ω, with the left (or following) base-line turned upwards. The curved or horseshoe part is very faint, and has many stars in it; the preceding base-line hardly visible. Its light is not equable, but blotty"†.

Lord OXMANTOWN informs me that in the observations of this nebula at Birr Castle there is no mention of resolvability; and that "the central part to the right of star α consists of bunches or patches of bright nebulosity, with fainter nebulosity intervening."

The spectrum of this nebula indicates that it possesses a gaseous constitution. One bright line only was seen, occupying in the spectrum apparently the same position as the brightest of the lines of nitrogen. When the slit was made as narrow as the intensity of the light would permit, this bright line was not so well defined as the corresponding line in some of the other nebulæ under similar conditions of the slit, but remained nebulous at the edges.

When the brightest portion of the nebula containing the nucleus or "bright knot" was brought upon the slit, in addition to the bright line a faint narrow continuous spectrum was seen.

The bright knot appeared in my telescope smaller and more condensed than it is represented in the drawings of Sir JOHN HERSCHEL.

[No. 4572. 2075 h. 16 H. IV. R.A. $20^h\ 16^m\ 7^s{\cdot}9$. N.P.D. 70° 20′ 19″·3. A planetary nebula; bright; pretty small; round; four stars near.]

"Rather hazy at the edges, but not materially brighter in the middle, but no hollow. It has four stars near it like satellites. Diameter in R.A. 30″±. Its light is a little mottled, but it is well defined"‡.

Lord ROSSE remarks, "This planetary nebula is a beautiful little spiral. Star or bright nucleus north following the middle"§.

"Dieser Nebel hat sich seit 30 Jahren bestimmt nicht nachweisbar bewegt. Klein aber ziemlich hell, 25″ diam., rund und durchaus gleichförmig hell; erscheint in der That wie eine Nebelscheibe."—D'ARREST ‖.

* "Mr. MASON declares the upper and larger knot to be irresolvable by his telescope (a reflector of 12 inches aperture and 14 feet focal length). In this particular my observations of 1835 and 1837 so far agree, that its resolvability is not mentioned in words or indicated in the diagrams made on those occasions."—Sir JOHN HERSCHEL, 'Results of Astronomical Observations at the Cape of Good Hope,' p. 7, and pl. 2, fig. 1.

† Philosophical Transactions, 1833, p. 461, and Plate XII. fig. 35.

‡ Philosophical Transactions, 1833, p. 467, and Plate XIII. fig. 47.

§ Ibid. 1861, p. 733, and Plate XXVII. fig. 34.

‖ Beobachtungen der Nebelflecken und Sternhaufen, p. 349.

"Durchmesser gemessen =27″."—SCHULTZ *.

The spectrum of this nebula consisted of one bright nebulous line of the same refrangibility as the brightest of the lines of nitrogen. No other lines were *certainly* seen.

The three brighter of the enclosing stars gave the usual stellar continuous spectrum.

Sir JOHN HERSCHEL remarks of these stars near the nebula, "The point to which I would draw attention is the frequent and close proximity to these objects (the planetary nebulæ) of minute stars, which suggest the idea of accompanying satellites" †.

D'ARREST, referring to these small stars, says (in 1856), "Von den Satelliten der planetarischen Nebelflecken die widergesehenen standen noch unverrück in den von Sir J. HERSCHEL so sorgfältig bestimmten Stellungen, oder können sich im Laufe der letzten Vierteljahrhunderts nur sehr kleine Grössen daraus entfernt haben.". . . . "Von etwa drittehalb Hundert Nebeln lässt es sich sehr wahrsheinlich machen, dass eigene jahrliche Bewegungen im Betrage von mehr als einer Bogensekunde nicht vorhanden sind. Streng beweisen endlich lässt sich vollständige Unmerklichkeit der Eigenbewegung während der letzten 60 Jahre bei einigen unter den planetarischen Nebelflecken" ‡.

[No. 4499. 2043 h. 38 H. VI. R.A. $19^h\ 24^m\ 53^s$. N.P.D. 81° 3′ 37″·8. Considerably bright; small; irregularly round; well resolved.]

"A very small roundish cluster, 40″ diam., of very small stars, one brighter than the rest. It is like a nebula well resolved, and is a curious object. . . . . Doubtful if a resolved cluster, or a nebula of the first class."—Sir JOHN HERSCHEL §.

"Four stars in nebula, and two more on preceding edge."—Lord ROSSE ‖.

"Suspect more smaller stars" ¶.—Lord OXMANTOWN.

* Astron. Nachrichten, No. 1541.

† Philosophical Transactions, 1833, p. 500.

‡ Beobachtungen der Nebelflecken und Sternhaufen, p. 308.

Some observers describe indications of the occurrence of continual and very rapid variations in the light of some of the gaseous nebulæ. It must not be forgotten, however, that in the nebulæ only phenomena of enormous magnitude could be visible to us. Besides this consideration, in the constantly varying state of our atmosphere, and in the variation in the power of the eye to appreciate minute differences of relative brightness when the conditions of illumination of the object are different, we have probably a sufficient explanation of these phenomena.

M. O. STRUVE (in 1856) says, ". . . the general impression that I have derived from the observations of this year, has been that the central part of the nebula of Orion is in a state of continual change with regard to the brightness in different parts of it. Even with the best definition, its appearances were to me on no evening entirely agreeing with those on the next or any other night."—Monthly Notices Royal Astron. Soc. vol. xvii. p. 230.

Dr. A. SCHULTZ (in 1865) observes of No. 4234, 1970 h., "Der Nebel flammt nicht in gewöhnlicher Weise, zeigt aber eine anaufhörlich gleichmässige Dilatation und Contraction." And also of No. 4572, 2075 h., "Momentan werschwindet die Nebulosität ganz (?) und der Nebel zeigt sich wie ein sehr reicher gedrängter Sternhaufen."—Astronom. Nachrichten, No. 1541.

§ Philosophical Transactions, 1833, p. 464.

‖ Ibid. 1861, p. 732.

¶ This observation, and those of other nebulæ to which the name of Lord OXMANTOWN is attached, have been kindly extracted for me from the observations made at Birr Castle.

The spectrum of this nebula, or at least of some parts of it, is almost certainly of the order which indicates that the source of the light is gaseous matter. I believe that the spectrum consists of one bright line. The object, however, is very faint, and the determination of its spectrum with my instrument very difficult. I examined the light of this nebula several times, with eyepieces of different powers applied to the small telescope of the spectroscope, but in all the observations I was confirmed in the opinion that the greater part at least of the light is monochromatic.

Probably there is, in addition to the bright line or lines, a faint continuous spectrum, which may belong to the stars which are visible within the nebula.

[No. 4827. 2178 h. 705 H. II. R.A. $22^h\ 35^m\ 6^s{\cdot}6$. N.P.D. $29°\ 27'\ 5''{\cdot}4$. Bright; small; round; gradually very little brighter in the middle; easily resolvable.]

"Planetary?"—Lord Rosse *.

"Three stars preceding. Resolvable?"—Lord Oxmantown.

One bright line only was distinctly seen in the spectroscope.

On account of the faintness of the object, I am unable to say whether any other fainter lines are also present, or a faint continuous spectrum.

[No. 4627. 2099 h. 192 H. I. R.A. $20^h\ 56^m\ 17^s{\cdot}5$. N.P.D. $35°\ 59'\ 39''{\cdot}6$. Considerably bright; large; barely resolvable; two stars attached.]

"Has an appearance of two nuclei or points of greatest condensation; it touches a fine double star."—Sir John Herschel †.

"The nebula has three knots in it."—Lord Rosse ‡.

"No mention of resolvability."—Lord Oxmantown.

The different knots of this nebula give a spectrum indicating gaseity, though in the examination of some parts of the nebula I suspected the presence of a faint continuous spectrum as well. The continuous spectrum may possibly belong to the small stars which are represented in Lord Rosse's drawing of this object.

One bright line only was distinctly seen, of apparently the same refrangibility as the brightest of the nitrogen line. This bright line appeared by glimpses to be double. Possibly this appearance was due to the presence near it of a second line. The faintness of the light did not permit the slit to be made sufficiently narrow for the determination of this point.

[[No. 385. 76 M. R.A. $1^h\ 33^m\ 28^s{\cdot}5$. N.P.D. $39°\ 8'\ 52''{\cdot}4$. Very bright; preceding of double nebula.

No. 386. 193 H. 1. R.A. $1^h\ 33^m\ 37^s{\cdot}5$. N.P.D. $39°\ 7'\ 27''{\cdot}4$. Very bright; following of double nebula.]

Both parts of this double nebula give a gaseous spectrum. The brightest only of the three lines usually present was *certainly* seen. The second line is probably also present.

I suspected a faint continuous spectrum at the preceding edge of No. 386.

* Philosophical Transactions, 1861, p. 735.

† Ibid. 1833, p. 469.

‡ Ibid. 1861, p. 734, and Plate XXX. fig. 37.

[No. 2343. 838 h. 97 M. R.A. $11^h\ 6^m\ 34^s{\cdot}8$. N.P.D. $34°\ 13'\ 38''{\cdot}2$. Planetary; very bright; very large; round; very gradually, very suddenly brighter in the middle.]

"A large uniform nebulous disk, diameter $19^s{\cdot}0$ in R.A. Quite round, very bright, not sharply defined, but yet very suddenly fading away to darkness."—Sir JOHN HERSCHEL*.

"Two stars considerably apart in the central region, dark penumbra round each spiral arrangement, with stars as apparent centres of attraction. Stars sparkling in it; resolvable."—Lord ROSSE†.

"Two stars were easily seen in this nebula formerly; since 1850 only one has been seen. Not observed since April 1864."—Lord OXMANTOWN.

The spectrum consists of the two brighter of the lines usually present. A continuous spectrum is doubtful. Once or twice a very faint continuous spectrum was suspected. —June 1866.]

§ III. *Observations of Nebulæ the spectra of which are apparently continuous.*

[No. 105. 44 h. 18 H. V. R.A. $0^h\ 32^m\ 45^s{\cdot}4$. N.P.D. $49°\ 4'\ 49''{\cdot}8$. Very bright; very gradually very much brighter in the middle.]

"Very large, much extended. Sharp nucleus, round which for some distance the nebula is bright, and then suddenly decreases; spirality suspected."—Lord ROSSE‡.

"Small stars seen on one occasion in the nucleus."—Lord OXMANTOWN.

Spectrum continuous.

[No. 307. 117 h. 151 H. I. R.A. $1^h\ 17^m\ 26^s{\cdot}8$. N.P.D. $81°\ 11'\ 50''{\cdot}3$. Very bright; much brighter in the middle.]

Spectrum continuous.

[No. 575. 242 h. 156 H. I. R.A. $2^h\ 31^m\ 38^s$. N.P.D. $51°\ 32'\ 45''{\cdot}9$. Very bright; very large; very much extended; very much brighter in the middle§.]

"Six stars seen in it distinctly, others suspected about centre. Nucleus suspected to be composed of stars."—Lord OXMANTOWN.

Centre of the nebula very bright. The spectrum of this bright central part alone was satisfactorily seen. This spectrum is continuous.

[No. 1949. 649 h. 81 M. R.A. $9^h\ 43^m\ 48^s{\cdot}9$. N.P.D. $20°\ 16'\ 10''$. Extremely bright; extremely large; gradually, suddenly very much brighter in the middle.]

Spectrum continuous; the red end of the spectrum wanting or very faint.

[No. 1950. 82 M. R.A. $9^h\ 43^m\ 52^s{\cdot}3$. N.P.D. $19°\ 34'\ 16''{\cdot}3$. Very bright; very large; very much extended, "a beautiful ray."]

Spectrum continuous. The absence or great faintness of the red portion of the spectrum more marked than in the spectrum of No. 1949.

[No. 3572. 1622 h. 51 M. R.A. $13^h\ 23^m\ 55^s{\cdot}4$. N.P.D. $42°\ 5'\ 4''$. Remarkable; nucleus and ring (*h*); spiral (R).]

* Philosophical Transactions, 1833, p. 402, also Plate X. fig. 32.

† Ibid. 1850, p. 513, and Plate XXXVII. fig. 2. ‡ Ibid. 1861, p. 709.

§ See also drawing by Lord ROSSE, Philosophical Transactions, 1861, Plate XXX. fig. 5.

"The outer nucleus unquestionably spiral with a twist to the left."—Lord Rosse*.

"Both nuclei resolved; brighter parts of spiral branches suspected to be resolved. Stars innumerable, though I feel satisfied that it is not a cluster."—Lord Oxmantown.

"Nos observations n'accusent aucun changement dans la position relative des deux têtes dans l'intervalle de 13 ans."—O. Struve†.

Each of the bright centres brought successively upon the slit. Spectrum continuous. A suspicion that some parts of the spectrum were abnormally bright relatively to the other parts.

[No. 2841. 1175 h. 43 H. V. R.A. $12^h\,12^m\,1^s{\cdot}7$. N.P.D. $41°\,55'\,40''{\cdot}6$. Very bright; very large; suddenly brighter in the middle; bright nucleus.]

"A very large bright extended nebula; much mottled."—Lord Rosse‡.

Spectrum continuous. A suspicion of unusual brightness about the middle part of the spectrum.

[No. 3474. 1570 h. 63 M. R.A. $13^h\,9^m\,31^s{\cdot}9$. N.P.D. $47°\,13'\,45''{\cdot}3$. Very bright; large; very suddenly much brighter in the middle; bright nucleus.]

"Spiral? darkness south following nucleus."—Lord Rosse§.

Spectrum continuous.

[No. 3636. 1663 h. 3 M. R.A. $13^h\,35^m\,40^s$. N.P.D. $60°\,55'\,6''$. Cluster; extremely bright.]

"Ein leicht auflöslicher Hauf zahllosen Sterne, in der Mitte zu einem einzigen Lichte von grosser helligkeit zusammenlaufend."—D'Arrest‖.

Spectrum continuous.

[No. 4058. 1909 h. 215 H. I. R.A. $15^h\,2^m\,36^s{\cdot}3$. N.P.D. $33°\,41'\,39''{\cdot}4$. Very bright; considerably large; gradually brighter in the middle.]

"None of the component stars to be seen. Resolvability strongest near nucleus."—Lord Oxmantown.

Spectrum continuous.

[No. 4159. 1945 h. R.A. $15^h\,58^m\,49^s{\cdot}9$. N.P.D. $81°\,31'\,23''{\cdot}2$. Star 7th mag. in photosphere.]

No unusual appearance was detected in the continuous spectrum of the star.

[No. 4230. 1968 h. 13 M. R.A. $16^h\,36^m\,41^s{\cdot}2$. N.P.D. $53°\,16'\,19''{\cdot}4$. Cluster; extremely bright.]

Spectrum of the central blaze continuous. Spectrum ends abruptly in the orange. The light of the brighter part is not uniform; probably it is crossed either by bright lines or by lines of absorption.

[No. 4238. 1971 h. 12 M. R.A. $16^h\,39^m\,58^s{\cdot}1$. N.P.D. $91°\,41'\,47''{\cdot}4$. Cluster; very bright.]

"Hairy branches with slightly spiral arrangement."—Lord Oxmantown.

* Philosophical Transactions, 1861, p. 728; also ibid. 1850, Plate XXXV. fig. 1.

† Bulletin de l'Académie Imp. des Sciences de St. Pétersbourg, tom. vii. p. 361.

‡ Philosophical Transactions, 1861, p. 725. § Ibid. p. 729.

‖ Beobachtungen der Nebelflecken und Sternhaufen, p. 338.

Spectrum continuous.

[No. 4244. 50 H. IV. R.A. $16^h\ 43^m\ 6^s{\cdot}4$. N.P.D. $42°\ 8'\ 38''{\cdot}8$. Very bright; large. round; disk + faint, barely resolvable, border.]

"Eine kleine Nebelsheibe, hell = ✳9 Gr., umgeben von einer merklich schwächern Nebelhülle; kreisrund 1′ diam. Ruhiges Licht, bläulich."—D'Arrest*.

Spectrum continuous. No appearance of bright lines when the slit was made narrow.

[No. 4256. 10 M. R.A. $16^h\ 49^m\ 47^s{\cdot}6$. N.P.D. $93°\ 52'\ 6''{\cdot}8$. Cluster; bright; well resolved.]

"The most important stars take a spiral arrangement."—Lord Oxmantown.

Spectrum continuous.

[No. 4315. 14 M. R.A. $17^h\ 30^m\ 16^s$. N.P.D. $93°\ 9'\ 25''$. Cluster; bright; well resolved.]

Spectrum continuous.

[No. 4357. 3719 h. 199 H. II. R.A. $17^h\ 54^m\ 13^s{\cdot}9$. N.P.D. $98°\ 56'\ 37''{\cdot}3$. Pretty bright; pretty large; round; partially resolved.]

Spectrum of the central, brighter part of the nebula continuous. As far as the light permitted, the marginal portion of the nebula was also examined, and appeared to give a continuous spectrum.

[No. 4437. 2019 h. 11 M. R.A. $18^h 43^m\ 37^s{\cdot}2$. N.P.D. $96°\ 26'\ 7''{\cdot}6$. Cluster; very bright.]

"Stars curiously broken up into groups."—Lord Oxmantown.

The continuous spectra of all the brighter stars of this cluster were separately visible. When the clockwork of the equatoreal was stopped, an interesting spectacle was presented by the flashing in rapid succession of the linear spectra of the minute stars of the cluster as they passed before the slit.

In no part of the cluster was any trace of bright lines detected†.

[No. 4441. 3762 h. 47 H. I. R.A. $18^h\ 45^m\ 29^s{\cdot}2$. N.P D. $98°\ 52'\ 8''{\cdot}5$. Cluster; well resolved.]

Spectrum continuous.

[No. 4473. Auw. N. 44. R.A. $19^h\ 4^m\ 4^s{\cdot}8$. N.P.D. $89°\ 11'\ 51''$. Pretty bright‡.]

Spectrum continuous.

[No. 4485. 2036 h. 56 M. R.A. $19^h\ 11^m\ 7^s{\cdot}2$. N.P.D. $60°\ 3'\ 41''{\cdot}6$. Cluster; bright; well resolved.]

Spectrum continuous. Suspicion of unusual brightness in the middle part of the spectrum.

* Beobachtungen der Nebelflecken und Sternhaufen, p. 341.

† This absence of any indication of gaseous matter is in accordance with telescopic observation. D'Arrest remarks of this cluster, "Mit Verg. 11 zerfällt der Sternhauf in deutlich gesonderte gruppen mit leeren zwischenräumen."—Beobach. der Nebelflecken und Sternhaufen, p. 346.

Lord Rosse observes:—"In such objects as clusters we find no new feature; nothing which had not been seen with instruments of inferior power."—Philosophical Transactions, 1844, p. 322.

‡ "This is the nebula discovered by Mr. Hind on March 30, 1845. It was observed in May 1852 as a nebula of the first class; subsequently as 'pretty faint and diluted.' M. Auwers found it 'surprisingly faint,' and of the second class at the highest."—Philosophical Transactions, 1864, p. 38.

[No. 4586. 2081 h. R.A. $20^h\ 27^m\ 19^s{\cdot}8$. N.P.D. 83° 3′ 41″·3. Bright cluster.]

Spectrum continuous.

[No. 4625. 2097 h. 52 H. I. R.A. $20^h\ 54^m\ 43^s{\cdot}8$. N.P.D. 74° 21′ 51″·7. Bright; pretty large; round; gradually brighter in the middle.]

"Round. Bright middle."—Lord Rosse*.

Spectrum continuous.

[No. 4600. 2088 h. 15 H. V. R.A. $20^h\ 39^m\ 53^s$. N.P.D. 59° 47′ 14″·8. Pretty bright; *k* Cygni involved.]

"It is very long and winding, and runs northward from *k* full 2 fields' breadth (30″). The nebulosity is milky, and does not seem to arise from small stars in the Milky Way ill seen."—Sir John Herschel†.

"This nebula resembles the Milky Way, and is full of dark uneven rifts or lanes. There are portions of its preceding edge clearly resolvable."—Lord Rosse‡.

I was not able to obtain a satisfactory spectrum of the nebula. The spectrum of the involved star was carefully examined. No peculiarity was observed in the continuous spectrum of the star. I have, however, the impression that the spectrum of the star, from about F towards the more refrangible end, appeared bright relatively to the other part. This might arise from groups of dark lines in the less refrangible portion of the spectrum.

[No. 4760. 2149 h. 207 H. II. R.A. $22^h\ 1^m\ 37^s{\cdot}4$. N.P.D. 59° 20′ 35″·6. Bright; extremely resolvable.]

"There is no doubt this nebula is a cluster."—Lord Oxmantown.

Spectrum continuous.

[No. 4815. 2172 h. 53 H I. R.A. $22^h\ 30^m\ 39^s{\cdot}5$. N.P.D. 56° 20′ 5″·6. Bright; pretty large; suddenly much brighter in the middle§.]

"Stars sparkling near centre."—Lord Oxmantown.

Spectrum continuous.

[No. 4821. 2173 h. 233 H. II. R.A. $22^h\ 30^m\ 44^s$. N.P.D. 66° 55′ 34″·6. Considerably bright; small; very suddenly much brighter in the middle, star 11th mag.]

Spectrum continuous.

[No. 4879. 2199 h. 251 H. II. R.A. $22^h\ 53^m\ 8^s$. N.P.D. 74° 46′ 10″. Pretty bright; very gradually brighter in the middle.]

Spectrum continuous.

[No. 4883. 2201 h. 212 H. II. R.A. $22^h\ 54^m\ 17^s{\cdot}6$. N.P.D. 60° 36′ 32″·2. Considerably bright; gradually much brighter in the middle; barely resolvable.]

"Centre almost certainly resolvable."—Lord Oxmantown.

The spectrum does not consist of one or two lines only. I believe that it is continuous.

The discovery by means of prismatic observation, that some of the nebulæ are gaseous

* Philosophical Transactions, 1861, p. 734. † Ibid. 1833, p. 468. ‡ Ibid. 1861, p. 733.

§ See drawing by Lord Rosse, Philosophical Transactions, 1861, Plate XXX. fig. 39.

in constitution, invests these objects with a new importance to the theories of cosmical science. A first consideration of these nebulæ would suggest that we have now evidence from observation of the existence of that primordial nebulous matter required by the theories of Sir WILLIAM HERSCHEL and LAPLACE*. But though it should be found ultimately that, in some of its forms, the theory of the development of aëriform matter into suns and planets is a true representation of the mode of formation of the universe, still it would show a want of the strict caution which experimental science demands in the interpretation of observed facts, to explain the phenomena presented by the gaseous nebulæ in connexion with the requirements of a theory which at present is not more than a speculation. In a paper "On the Spectrum of the Great Nebula in Orion†," I stated, as the result of the observations which I had then made, the provisional opinion that the gaseous nebulæ may belong possibly to an order of cosmical bodies distinct from that represented by the sun and fixed stars. In this connexion it may be remarked that my examination of the light of Comet I. 1866‡ shows that a close relation probably exists between nebular and cometary matter.

As further contributions towards a future determination of the true rank and cosmical relations of these nebulæ, I proceed to give the results of some observations on the intensity of their light, and also measures of some of the planetary nebulæ.

§ IV. *On a Mode of determining the Brightness of some of the Nebulæ.*

As long as the nebulæ were regarded as aggregations of discrete stars separately invisible, it was not possible by any photometric estimation of the light from them which reaches the earth, to ascertain the intrinsic brilliancy of the suns of which the nebulæ were supposed to consist. For since these stars have no sensible magnitude even when separately visible, their intrinsic splendour could not be estimated from their brightness to an observer on the earth, so long as their distance from our system remained unknown.

Now, however, that the application of prismatic analysis to the light of the nebulæ has shown that some of these objects consist of luminous gas existing in masses which are probably continuous, though, indeed, in some cases, this aëriform matter appears to be aggregated into portions of unequal brilliancy, the intrinsic brightness of these nebulæ may be estimated from the earth, though their distance from us is unknown. The nebulæ are not points without sensible magnitude in the telescope, but present surfaces, in some cases, subtending a considerable angle. The brilliancy of a luminous surface, when beyond the earth's atmosphere, does not vary with its distance from the observer, except as it may be diminished by a possible power of extinction belonging to celestial space. For the diminution of brightness of a luminous surface, as it becomes

* A cosmical theory, which may perhaps be described as the converse of the nebular hypothesis, has been recently suggested by Professor E. W. BRAYLEY: see Proceedings of the Royal Society, vol. xiv. p. 120.

† Proceedings of the Royal Society, vol. xiv. p. 39. ‡ Ibid. vol. xv. p. 5.

more distant, takes place in the same proportion as the surface decreases in apparent magnitude; as long therefore as a distant object remains of sensible size in the telescope, the object retains its original brightness unaltered. If, therefore, the light of these nebulæ be compared with a luminous body on the earth, we can obtain approximately the intrinsic intensity of their light in terms expressing a proportion to the terrestrial light selected for comparison. The values of the intrinsic brilliancy of the nebulæ obtained in this way must be smaller than the true amount, because they are measures of the light after it has traversed an unknown extent of celestial space, and has passed through the earth's atmosphere. The amount by which, from these causes, the estimated brightness of the nebulæ would be too small must remain for the present unknown, since we have no data by which this loss could be even estimated*.

Notwithstanding these errors of unknown amount with which the results of a comparison of the nebulæ with a terrestrial source of light must stand affected, an attempt to discover, even approximately, the intrinsic brightness of the gaseous nebulæ has some importance in connexion with the physical constitution which prismatic analysis has shown these objects to possess. The coincidence of two of the three lines forming the spectra of some of the nebulæ, severally with a line of hydrogen and the brightest line of nitrogen, appears to indicate that they consist of aëriform matter. Highly transparent bodies, such as these gases are, emit when heated but a feeble light compared with that which would be radiated, at the same temperature, by more opake bodies. The invisibility of these nebulæ to the naked eye, though some of them are of considerable apparent size, shows that they possess a very feeble degree of luminosity†.

Besides these considerations, by means of similar photometric observations made at considerable intervals of time, it would be possible to ascertain whether the intrinsic brightness of the gaseous nebulæ is undergoing increase or diminution, or is subject to a periodic variation.

* In 1744 Chéseaux was led by theoretical speculations to assume that light is gradually extinguished in its passage through space. By somewhat similar reasoning Olbers (in 1823) assumed that a star loses the $\frac{1}{800}$ of its intensity in traversing a distance of space equal to that which separates Sirius from the sun.—Über die Durchsichtigkeit des Weltraums, Bode's Jahrbuch, 1826, s. 110–121.

The elder Struve, from an examination of Sir W. Herschel's telescopic gauges of the Milky Way, supposed that a star of the sixth magnitude has lost $\frac{7}{100}$ of its original intensity, a star of the ninth magnitude $\frac{29}{100}$, and the smallest star visible in Sir William Herschel's telescope $\frac{88}{100}$.—Études d'Astronomie Stellaire, p. 89.

A fundamental element of the reasoning by which Struve obtained these values was, that the stars are distant from our system in the inverse ratio of their apparent brightness. Since, however, the stars to which observation assigns the largest parallax, 61 Cygni and α Centauri, are less bright than other stars, in which no parallax, or a much smaller one only, has been detected (not to refer to what may be regarded as an exceptional case, the great inequality in magnitude of some binary stars), this assumption that the apparent brightness of stars depends alone upon their distance, has been shown not to be true in the cases in which it has been confronted with observation.

† "It is evident that the intrinsic splendour of their surfaces, if continuous, must be almost infinitely less than that of the sun."—Sir John Herschel, Outlines of Astronomy, p. 646, 7th edit.

For the purpose of making these observations I had constructed, by Mr. G. DOLLOND, an instrument in which are combined two forms of apparatus contrived by the Rev. W. R. DAWES, F.R.S., and described by him under the names of "An aperture-diminishing eyepiece," and "A Photometer of Neutral-tint Glass*."

This instrument, which is adapted to the eye-end of my achromatic telescope, consists essentially, first, of a diaphragm drilled with small holes moveable within the focus of the telescope, which diminishes the aperture of the telescope in proportion as it is advanced towards the object-glass; and secondly, of two graduated wedges of neutral-tint glass, which slide in front of the convex lenses with which the focal image is viewed. The aperture in the diaphragm which was used in the following observations has a diameter of 0·06 inch. The diaphragm is moved by a screw, and its position is read off upon a scale divided into tenths of an inch. The photometer wedges are 4 inches in length and divided into forty parts.

The observations were made in the following way.

The diaphragm was placed so that all the pencils from the object-glass passed through the small aperture without diminution. The nebulæ were viewed through the wedges of neutral-tint glass. These were made to slide before the eye, until the exact part of one of the wedges was found, at which the nebula was extinguished.

On August 25, 1865, a night of more than usual clearness, several estimations were made of each of the three nebulæ, No. 4628. 1 H. IV., the annular nebula in Lyra, and the Dumb-bell nebula. In each case the estimation applies to the brightest part of the nebula.

The source of light selected as a standard of comparison was a sperm candle of the size known as "six to the pound."

The rate of burning of this candle on three occasions was—

August	26	.	35	minutes	lost in	weight	132 grs.	=157·8 grs. per hour.
„	31	.	38	„	„	„	142 grs.	=160·8 grs. „
September	7	.	41	„	„	„	148 grs.	=157·8 grs. „

It was found necessary to diminish greatly the light of the candle in order to bring it within the range of comparison afforded by the moveable diaphragm.

For this purpose a thick plate, with parallel sides, of neutral-tint glass was placed before the flame of the candle. An examination of the neutral-tint glass with a prism showed that the absorptive power of the glass for all refrangibilities in the brighter portions of the spectrum was very nearly uniform. The amount of diminution of the light of the candle effected by the plate of neutral glass was measured by a BUNSEN'S photometer. When the light passed through the neutral glass, the candle required to be placed at a distance of 6·5 inches to cause the ungreased central spot of the photometer to disappear. Without the glass, the disappearance took place when the candle

* Monthly Notices, Royal Astronomical Society, vol. xxv. p. 229.

was removed to a distance of 126·25 inches. The disappearance was viewed with a small telescope. The numbers adopted are the mean of several observations, the close accordance of which showed that the fixed light behind the screen had remained of constant intensity. The ratio of the squares of the distances shows that the light of the candle was reduced by the neutral-tint glass to the $\frac{1}{377}$ part of its original intensity.

The candle, placed in a lantern and screened by the neutral-tint glass, was fixed on the roof of a house at a distance of 440 yards from the observatory*. It was desirable that the candle should be at some distance, in order that its image in the telescope should be formed at nearly the same distance from the object-glass as the images of celestial objects. Besides, it was convenient that the flame of the candle should appear small, when viewed with the convex lens, magnifying on the telescope 101 diameters, with which the nebulæ had been observed.

The image of the flame of the candle in the telescope was viewed through the same parts of the wedges of neutral-tint glass at which the nebulæ had been observed to become invisible. By means of the moveable diaphragms, and also independently by means of diaphragms placed before the object-glass, the apertures of the object-glass were found at which the flame of the candle became extinguished at the parts of the wedges at which the nebulæ had been observed to disappear.

	Sept. 7, 1865.	Jan. 19, 1866.
Aperture corresponding to nebula in Lyra . .	2·09 inches.	2·00 inches.
„ „ Dumb-bell nebula . .	1·06 inch.	1·20 inch.
„ „ Nebula No. 4628. 1 H. IV.		4·0 inches.

Taking into consideration the circumstances of the observations, I adopt for the

Dumb-bell nebula an aperture of . . .	1·10 inch.
Annular nebula in Lyra an aperture of .	2·00 inches.
Nebular No. 4628 an aperture of . . .	4·00 inches.

The disappearance of the nebulæ with the neutral-tint glass wedges had been observed with the full aperture of the telescope (8 inches), therefore the ratios of the areas of the aperture corresponding to the diameters of 1·10 inch, 2·00 inches, and 4·00 inches, to the area of the full aperture of the telescope, will give the intensities of the nebulæ in terms of the candle screened with the neutral-tint glass. The results are—

Dumb-bell nebula	$=\frac{1}{52}$
Nebula in Lyra	$=\frac{1}{16}$
Nebula No. 4628	$=\frac{1}{4}$

of the intensity of the obscured candle.

The neutral-tint glass reduces the intensity of the candle to the $\frac{1}{377}$ part, therefore the

* I gratefully acknowledge the assistance of my friend, Mr. S. B. Kincaid, F.R.A.S., who took the management of the candle.

intensities of the nebulæ in terms of the intensity of the unscreened flame of the sperm candle are—

Nebula No. 4628 . . . . $= \frac{1}{1508}$,
Annular nebula in Lyra . . $= \frac{1}{6032}$,
Dumb-bell nebula . . . $= \frac{1}{19604}$.

It may be remarked, in connexion with these values of the intensity of the light of these nebulæ, that nebula No. 4628 gives a spectrum of three bright lines, and also a faint continuous spectrum. The nebula in Lyra and the Dumb-bell nebula give one bright line only.

§ V. *Measures of some of the Nebulæ.*

If great physical changes, such as subsidence and condensation, of the magnitude necessary for the conversion of the nebulæ into suns are taking place in these objects, an indication of the advance of these processes might perhaps be obtained by measurements, taken at considerable intervals, of such of the nebulæ as are suitable for this purpose. There are several of the planetary nebulæ which give a gaseous spectrum, which in telescopes of moderate power have disks sufficiently well defined for micrometric measurement. Measures of these nebulæ would be comparable with future measures obtained with telescopes of similar power.

Some months since I invited the Rev. W. R. Dawes, F.R.S., to take measures of the diameters of several of these objects. Ill health has unfortunately prevented him from measuring more than one nebula, No. 4234, 5Σ. Mr. Dawes writes, "So bright and yet so imperfectly defined, like the heads of some comets. The moon was near the horizon, yet I found that I could get hold of more of it with high powers than with lower. It appeared rather suddenly to fade away at the edges, and to have a sort of faint halo round it, which, however, was not distinctly separate from the brighter centre. I obtained four sets of measures of the diameter which was parallel to the equator; but thought that the form was rather elliptic, the equatorial diameter being the greater. The four sets were obtained with powers 148, 218, 292, and 382; that with 148 appearing to be far less certain than the others. The illumination of the field necessary to show the wires with power 148 seemed to diminish the visibility of the nebula more than did the increase of power; with which the wires were sufficiently seen with much less illumination. The results were—

With power	148	diam.	$=14''\cdot23$
„	218	„	$=15\cdot76$
„	292	„	$=15\cdot70$
„	382	„	$=16\cdot23$

} Mean of all $15''\cdot5$.

"Mean of the three higher powers $=15''\cdot9$, which I consider worthy of much more confidence. I could not see the fainter halo sufficiently well with any illumination to get safe measures of it. These results refer to the brighter disk only."

Measures of this nebula by former observers—

1833,	diam. =	8″	Sir JOHN HERSCHEL*.
1856, March,	diam. =	6	D'ARREST†
1856, June,	diam. =	8	D'ARREST†
1864, August,	diam. =	9·6	SCHULTZ‡
	=	14·5	AUWERS?‡

Nebula No. 4514. 2050 h. 73 H. IV. I made careful measures of this object on two occasions. Wire micrometer with dark ground illumination.

1865. Nov. 25. Power 333. Mean of six measures 31″·06.

1865. Dec. 15. Power 680. Mean of three measures 30″·66.

I think the measures of Dec. 15 are entitled to more confidence than those of Nov. 25. I should prefer to take as the most probable value—Diam. in R.A. =30″·8.

1833. Diam. in R.A.=45″·5. Sir JOHN HERSCHEL§.

1864. Diam. in R.A.= 0′·4. SCHULTZ‖.

* Philosophical Transactions, 1833, p. 458.

† Beobachtungen der Nebelflecken und Sternhaufen, p. 341.

‡ Astronom. Nachrichten, No. 1541, p. 70.

§ Philosophical Transactions, 1833, p. 464.

‖ Astronom. Nachrichten, No. 1541.