XIII. *On the Spectra of some of the Nebulæ.* *By* WILLIAM HUGGINS, *F.R.A.S.* *A Supplement to the Paper "On the Spectra of some of the Fixed Stars.* *By* WILLIAM HUGGINS, *F.R.A.S., and* W. A. MILLER, *M.D., LL.D., Treas. and V.P.R.S." Communicated by Professor* W. A. MILLER, *M.D., LL.D.*

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THE concluding paragraphs of the preceding paper refer to the similarity of essential constitution which our examination of the spectra of the fixed stars has shown in all cases to exist among the stars, and between them and our sun.

It became therefore an object of great importance, in reference to our knowledge of the visible universe, to ascertain whether this similarity of plan observable among the stars, and uniting them with our sun into one great group, extended to the distinct and remarkable class of bodies known as nebulæ. Prismatic analysis, if it could be successfully applied to objects so faint, seemed to be a method of observation specially suitable for determining whether any essential physical distinction separates the nebulæ from the stars, either in the nature of the matter of which they are composed, or in the conditions under which they exist as sources of light. The importance of bringing analysis by the prism to bear upon the nebulæ is seen to be greater by the consideration that increase of optical power alone would probably fail to give the desired information; for, as the important researches of Lord ROSSE have shown, at the same time that the number of the clusters may be increased by the resolution of supposed nebulæ, other nebulous objects are revealed, and fantastic wisps and diffuse patches of light are seen, which it would be assumption to regard as due in all cases to the united glare of suns still more remote.

Some of the most enigmatical of these wondrous objects are those which present in the telescope small round or slightly oval disks. For this reason they were placed by Sir WILLIAM HERSCHEL in a class by themselves under the name of Planetary Nebulæ. They present but little indication of resolvability. The colour of their light, which in the case of several is blue tinted with green, is remarkable, since this is a colour extremely rare amongst single stars. These nebulæ, too, agree in showing no indication of central condensation. By these appearances the planetary nebulæ are specially marked as objects which probably present phenomena of an order altogether different from those which characterize the sun and the fixed stars. On this account, as well as because of their brightness, I selected these nebulæ as the most suitable for examination with the prism.

The apparatus employed was that of which a description was given at page 421. A second eyepiece was used in these observations, having a magnifying power of nine

diameters. For the greater part of the following observations on the nebulæ, the cylindrical lens is not necessary, and was removed from the instrument. The numbers and descriptions of the nebulæ, and their places for the epoch 1860, January 0, included within brackets, are taken from the last Catalogue of Sir JOHN HERSCHEL*.

[No. 4373. 37 H. IV. R.A. $17^h\ 58^m\ 20^s$. N.P.D. $23°\ 22'\ 9''{\cdot}5$. A planetary nebula; very bright; pretty small; suddenly brighter in the middle, very small nucleus.] In Draco.

On August 29, 1864, I directed the telescope armed with the spectrum apparatus to this nebula. At first I suspected some derangement of the instrument had taken place; for no spectrum was seen, but only a short line of light perpendicular to the direction of dispersion. I then found that the light of this nebula, unlike any other ex-terrestrial light which had yet been subjected by me to prismatic analysis, was not composed of light of different refrangibilities, and therefore could not form a spectrum. A great part of the light from this nebula is monochromatic, and after passing through the prisms remains concentrated in a bright line occupying in the instrument the position of that part of the spectrum to which its light corresponds in refrangibility. A more careful examination with a narrower slit, however, showed that, a little more refrangible than the bright line, and separated from it by a dark interval, a narrower and much fainter line occurs. Beyond this, again, at about three times the distance of the second line, a third, exceedingly faint line was seen. The positions of these lines in the spectrum were determined by a simultaneous comparison of them in the instrument with the spectrum of the induction spark taken between electrodes of magnesium. The strongest line coincides in position with the brightest of the air lines. This line is due to nitrogen, and occurs in the spectrum about midway between *b* and F of the solar spectrum. Its position is seen in Plate XI.†

The faintest of the lines of the nebula agrees in position with the line of hydrogen corresponding to FRAUNHOFER'S F. The other bright line was compared with the strong line of barium 2075‡: this line is a little more refrangible than that belonging to the nebula.

Besides these lines, an exceedingly faint spectrum was just perceived for a short distance on both sides of the group of bright lines. I suspect this is not uniform, but is crossed with dark spaces. Subsequent observations on other nebulæ induce me to regard this faint spectrum as due to the solid or liquid matter of the nucleus, and as quite distinct from the bright lines into which nearly the whole of the light from the nebula is concentrated.

In the diagram (fig. 5, Plate X.) the three principal lines only are inserted, for it would be scarcely possible to represent the faint spectrum without greatly exaggerating its intensity.

The colour of this nebula is greenish blue.

* Philosophical Transactions, Part. I. 1864, pp. 1–138.

† See also Philosophical Transactions, 1864, p. 156, and Plate I.

‡ Ibid. p. 156.

[No. 4390. 2000 h. Σ 6. R.A. $18^h\ 5^m\ 17^s{\cdot}8$. N.P.D. $83°\ 10'\ 53''{\cdot}5$. A planetary nebula; very bright; very small; round; little hazy.] In Taurus Poniatowskii.

The spectrum is essentially the same as that of No. 4373.

The three bright lines occupy the same positions in the spectrum, which was determined by direct comparison with the spectrum of the induction spark. These lines have also the same relative intensity. They are exceedingly sharp and well defined. The presence of an extremely faint spectrum was suspected. In connexion with this it is important to remark that this nebula does not possess a distinct nucleus.

The colour of this nebula is greenish blue.

[No. 4514. 2050 h. 73 H. IV. R.A. $19^h\ 41^m\ 7^s{\cdot}5$. N.P.D. $39°\ 49'\ 41''{\cdot}7$. A planetary nebula with a central star. Bright; pretty large; round; star of the 11th magnitude in the middle.] In Cygnus.

The same three bright lines were seen. Their positions in the spectrum were verified by direct comparison with the induction spark. In addition to these a spectrum could be traced from about D to about G of the solar spectrum. This spectrum is much stronger than the corresponding spectrum of 4373. This agrees with the greater brightness of the central star, or nucleus. The opinion that the faint continuous spectrum is formed alone by the light from the bright central point was confirmed by the following observation. When the cylindrical lens was removed, the three bright lines remained of considerable length, corresponding to the diameter of the telescopic image of the nebula; but the faint spectrum became as narrow as a line, showing that this spectrum is formed by light which comes from an object of which the image in the telescope is a point.

Lord Rosse remarks of this nebula, "A very remarkable object, perhaps analogous to H. 450"*.

The colour of this nebula is greenish blue.

[No. 4510. 2047 h. 51 H. IV. R.A. $19^h\ 36^m\ 3^s{\cdot}0$. N.P.D. $104°\ 28'\ 52''{\cdot}5$. A planetary nebula. Bright; very small; round.] In Sagittarius.

This nebula is less bright than those which have been described. The two brighter of the lines were well defined, and were directly compared with the induction spark. The third line was seen only by glimpses. I had a suspicion of an exceedingly faint spectrum.

The colour of this nebula is greenish blue.

Lord Rosse remarks, "Centre rather dark. The dark part is a little north preceding the middle"†.

[No. 4628. 2098 h. 1 H. IV. R.A. $20^h\ 56^m\ 31^s{\cdot}2$. N.P.D. $101°\ 55'\ 4''{\cdot}8$. An exceedingly interesting object. Planetary; very bright; small; elliptic.] In Aquarius.

The three bright lines very sharp and distinct. They were compared for position with the induction spark. Though this object is bright, an indication only of the faint

* Philosophical Transactions, Part III. 1861, p. 733. For a figure of H. 450 see Philosophical Transactions, 1850, Plate XXXVIII. fig. 15.

† Ibid. 1861, Part III. p. 732.

spectrum was suspected. This nebula contains probably a very small quantity of matter condensed into the liquid or solid state.

The colour of the light of this nebula is greenish blue.

Lord Rosse has not detected any central star, nor any perforation, as seen in some of the other planetary nebulæ. He represents it with ansæ, which probably indicate a nebulous ring seen edgeways*.

[No. 4447. 2023 h. 57 M. R.A. $18^h\ 48^m\ 20^s$. N.P.D. $57°\ 8'\ 57''{\cdot}2$. An annular nebula; bright; pretty large; considerably elongated.] In Lyra†.

The apparent brightness of this nebula, as seen in the telescope, is probably due to its large extent, for the faintness of its spectrum indicates that it has a smaller intrinsic brightness than the nebulæ already examined. The brightest of the three lines was well seen. I suspected also the presence of the next in brightness. No indication whatever of a faint spectrum. The bright line looks remarkable, since it consists of two bright dots corresponding to sections of the ring, and between these there was not darkness, but an excessively faint line joining them. This observation makes it probable that the faint nebulous matter occupying the central portion is similar in constitution to that of the ring. The bright line was compared with the induction-spark‡.

[No. 4964. 2241 h. 18 H. IV. R.A. $23^h19^m\ 9^s{\cdot}9$. N.P.D. $48°\ 13'\ 57''{\cdot}5$. Planetary; very bright; pretty small, round, blue.]

With a power of 600 this nebula appears distinctly annular. The colour of its light is greenish blue§. The spectrum formed by the light from this nebula corresponds with that of 37 H. IV. represented in fig. 5, Plate X.

* Philosophical Transactions, 1850, p. 507 and Plate XXXVIII. fig. 14.

† Lord Rosse, in his description of this nebula, remarks, "The filaments proceeding from the edge become more conspicuous under increasing magnifying power within certain limits, which is strikingly characteristic of a cluster; still I do not feel confident that it is resolvable."—Philosophical Transactions, 1844, p. 322 and Plate XIX. fig. 29.

In 1850 Lord Rosse further remarks, "I have not yet sketched it with the 6-feet instrument, because I have never seen it under favourable circumstances: the opportunities of observing it well on the meridian are comparatively rare, owing to twilight. It was observed seven times in 1848, and once in 1849. The only additional particulars I collect from the observations are that the central opening has considerably more nebulosity, and there is one pretty bright star in it, s. f. the centre, and a few other very minute stars. In the sky round the nebula and near it there are several very small stars which were not before seen; and therefore the stars in the dark opening may possibly be merely accidental. In the annulus, especially at the extremities of the minor axis, there are several minute stars, but there was still much nebulosity not seen as distinct stars."—Philosophical Transactions, 1850, p. 506.

"Nothing additional since 1844, except a star s. f. the middle."—Philosophical Transactions, 1861, p. 732.

‡ Already in 1850 Lord Rosse had discovered a connexion in general plan of structure between some of the nebulæ which present small planetary disks in ordinary telescopes, and the annular nebula in Lyra. His words are, "There were but two annular nebulæ known in the northern hemisphere when Sir John Herschel's Catalogue was published; now there are seven, as we have found that five of the planetary nebulæ are really annular. Of these objects, the annular nebula in Lyra is the one in which the form is the most easily recognized."—Philosophical Transactions, 1850, p. 506.

§ For Lord Rosse's observations of this nebula, see Philosophical Transactions, 1844, p. 323; ibid. 1850, p. 507 and Plate XXXVIII. fig. 13; ibid. 1861, p. 736 and Plate XXX. fig. 40.

In the spectrum of this nebula, however, in addition to the three bright lines, a fourth bright line, excessively faint, was seen. This line is about as much more refrangible than the line agreeing in position with F as this line is more refrangible than the brightest of the lines, which coincides with a line of nitrogen.

[No. 4532. 2060 h. 27 M. R.A. $19^h\,53^m\,29^s{\cdot}3$. N.P.D. $67°\,39'\,43''$. Very bright; very large; irregularly extended. Dumb-bell.] In Vulpecula.

The light of this nebula, after passing through the prisms, remained concentrated in a bright line corresponding to the brightest of the three lines represented in fig. 5, Plate X. This line appeared nebulous at the edges. No trace of the other lines was perceived, nor was a faint continuous spectrum detected.

The bright line was ascertained, by a simultaneous comparison with the spectrum of the induction spark, to agree in position with the brightest of the lines of nitrogen.

Minute points of light have been observed in this nebula by Lord Rosse, Otto Struve, and others; the spectra of these bright points, especially if continuous like those of stars, are doubtless invisible from excessive faintness.

By suitable movements given to the telescope, different portions of the image of the nebula formed in the telescope were caused successively to fall upon the opening of the slit, which was about $\frac{1}{10}$ inch by $\frac{1}{300}$ inch. This method of observation showed that the light from different parts of the nebula is identical in refrangibility, and varies alone in degree of intensity.

In addition to these objects the following were also observed:—

[No. 4294. 92 M. R.A. $17^h\,12^m\,56^s{\cdot}9$. N.P.D. $46°\,43'\,31''{\cdot}2$.] In Hercules. Very bright globular cluster of stars. The bright central portion was brought upon the slit. A faint spectrum similar to that of a star. The light could be traced from between C and D to about G.

Too faint for the observation of lines of absorption.

[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.] In Hercules. The spectrum similar to that of a faint star. No indication of bright lines.

[No. 116. 50 h. 31 M. R.A. $0^h\,35^m\,3^s{\cdot}9$. N.P.D. $49°\,29'\,45''{\cdot}7$.] The brightest part of the great nebula in Andromeda was brought upon the slit.

The spectrum could be traced from about D to F. The light appeared to cease very abruptly in the orange; this may be due to the smaller luminosity of this part of the spectrum. No indication of the bright lines.

[No. 117. 51 h. 32 M. R.A. $0^h\,35^m\,5^s{\cdot}3$. N.P.D. $49°\,54'\,12''{\cdot}7$. Very very bright; large; round; pretty suddenly much brighter in the middle.]

This small but very bright companion of the great nebula in Andromeda presents a spectrum apparently exactly similar to that of 31 M.

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.

[No. 428. 55 Androm. R.A. $1^h\ 44^m\ 55^s{\cdot}9$. N.P.D. $49°\ 57'\ 41''{\cdot}5$. Fine nebulous star with strong atmosphere.] The spectrum apparently similar to that of an ordinary star*.

[No. 826. 2618 h. 26 IV. R.A. $4^h\ 7^m\ 50^s{\cdot}8$. N.P.D. $103°\ 5'\ 32''{\cdot}2$. Very bright cluster.] In Eridanus. The spectrum could be traced from the orange to about the blue. No indication of the bright lines.

Several other nebulæ were observed, but of these the light was found to be too faint to admit of satisfactory examination with the spectrum apparatus.

It is obvious that the nebulæ 37 H. IV., 6 Σ., 73 H. IV., 51 H. IV., 1 H. IV., 57 M., 18 H. IV. and 27 M. can no longer be regarded as aggregations of suns after the order to which our own sun and the fixed stars belong. We have in these objects to do no longer with a special modification only of our own type of suns, but find ourselves in the presence of objects possessing a distinct and peculiar plan of structure.

In place of an incandescent solid or liquid body transmitting light of all refrangibilities through an atmosphere which intercepts by absorption a certain number of them, such as our sun appears to be, we must probably regard these objects, or at least their photo-surfaces, as enormous masses of luminous gas or vapour. For it is alone from matter in the gaseous state that light consisting of certain definite refrangibilities only, as is the case with the light of these nebulæ, is known to be emitted.

It is indeed *possible* that suns endowed with these peculiar conditions of luminosity may exist, and that these bodies are clusters of such suns. There are, however, some considerations, especially in the case of the planetary nebulæ, which are scarcely in accordance with the opinion that they are clusters of stars.

Sir JOHN HERSCHEL remarks of one of this class, in reference to the absence of central condensation, "Such an appearance would not be presented by a globular space uniformly filled with stars or luminous matter, which structure would necessarily give rise to an apparent increase of brightness towards the centre in proportion to the thickness traversed by the visual ray. We might therefore be inclined to conclude its real constitution to be either that of a hollow spherical shell or of a flat disk presented to us (by a highly improbable coincidence) in a plane precisely perpendicular to the visual ray"†. This absence of condensation admits of explanation, without recourse to the supposition of a shell or of a flat disk, if we consider them to be masses of glowing gas. For supposing, as we probably must do, that the whole mass of the gas is luminous, yet it would follow, by the law which results from the investigations of KIRCHHOFF, that the light emitted by the portions of gas beyond the surface visible to us, would

* "Looked at eight times, but saw no nebulous atmosphere."—Lord ROSSE, Philosophical Transactions, 1861, p. 712.

† Outlines of Astronomy, 7th edit. p. 646.

be in great measure, if not wholly, absorbed by the portion of gas through which it would have to pass, and for this reason there would be presented to us a *luminous surface* only*.

Sir JOHN HERSCHEL further remarks†, "Whatever idea we may form of the real nature of the planetary nebulæ, which all agree in the absence of central condensation, it is evident that the intrinsic splendour of their surfaces, *if continuous*, must be almost infinitely less than that of the sun. A circular portion of the sun's disk, subtending an angle of 1′, would give a light equal to that of 780 full moons, while among all the objects in question there is not one which can be seen with the naked eye." The small brilliancy of these nebulæ is in accordance with the conclusions suggested by the observations of this paper; for, reasoning by analogy from terrestrial physics, glowing or luminous gas would be very inferior in splendour to incandescent solid or liquid matter.

Such gaseous masses would be doubtless, from many causes, unequally dense in different portions; and if matter condensed into the liquid or solid state were also present, it would, from its superior splendour, be visible as a bright point or points within the disk of the nebula. These suggestions are in close accordance with the observations of Lord ROSSE.

Another consideration which opposes the notion that these nebulæ are clusters of stars is found in the extreme simplicity of constitution which the three bright lines suggest, whether or not we regard these lines as indicating the presence of nitrogen, hydrogen, and a substance unknown.

It is perhaps of importance to state that, except nitrogen, no one of thirty of the chemical elements the spectra of which I have measured has a strong line very near the bright line of the nebulæ. If, however, this line were due to nitrogen, we ought to see other lines as well; for there are specially two strong double lines in the spectrum of nitrogen, one at least of which, if they existed in the light of the nebulæ, would be easily visible‡. In my experiments on the spectrum of nitrogen, I found that the

* Sir WILLIAM HERSCHEL in 1811 pointed out the necessity of supposing the matter of the planetary nebulæ to have the power of intercepting light. He wrote:—"Admitting that these nebulæ are globular collections of nebulous matter, they could not appear equally bright if the nebulosity of which they are composed consisted only of a luminous substance perfectly penetrable to light..... Is it not rather to be supposed that a certain high degree of condensation has already brought on a sufficient consolidation to prevent the penetration of light, which by this means is reduced to a superficial planetary appearance?"

"Their planetary appearance shows that we only see a superficial lustre such as opaque bodies exhibit, and which could not happen if the nebulous matter had no other quality than that of shining, or had so little solidity as to be perfectly transparent."—Philosophical Transactions, 1811, pp. 314, 315.

† Outlines of Astronomy, 7th edit. p. 646.

‡ Philosophical Transactions, 1864, p. 154 and Plate I.

For the purpose of ascertaining whether the absence of the other bright lines of nitrogen might be connected with the presence of hydrogen, I arranged an apparatus in which, while the spectrum of the induction-spark in a current of nitrogen was being observed, a current of hydrogen could be introduced, and the propor-

character of the brightest of the lines of nitrogen, that with which the line in the nebulæ coincides, differs from that of the two double lines next in brilliancy. This line is more nebulous at the edges, even when the slit is narrow and the other lines are thin and sharp. The same phenomenon was observed with some of the other elements*. We do not yet know the origin of this difference of character observable among lines of the same element. May it not indicate a physical difference in the atoms, in connexion with the vibrations of which the lines are probably produced? The speculation presents itself, whether the occurrence of this one line only in the nebulæ may not indicate a form of matter more elementary than nitrogen, and which our analysis has not yet enabled us to detect.

Observations on other nebulæ which I hope to make, may throw light upon these and other considerations connected with these wonderful objects.

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tion of the two gases to each other easily regulated. With this apparatus the fading out of the bright lines of nitrogen, as the proportion of this gas to hydrogen was diminished, and again their increase in brilliancy when the current of nitrogen was made stronger, were carefully observed, but without detecting any marked variation in the relative brightness of the lines.

* Philosophical Transactions, 1864, pp. 143, 150.