XII. *On the Spectra of some of the Fixed Stars.*

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§ I. *Introduction.*

1. THE recent discovery by KIRCHHOFF of the connexion between the dark lines of the solar spectrum and the bright lines of terrestrial flames, so remarkable for the wide range of its application, has placed in the hands of the experimentalist a method of analysis which is not rendered less certain by the distance of the objects the light of which is to be subjected to examination. The great success of this method of analysis as applied by KIRCHHOFF to the determination of the nature of some of the constituents of the sun, rendered it obvious that it would be an investigation of the highest interest, in its relations to our knowledge of the general plan and structure of the visible universe, to endeavour to apply this new method of analysis to the light which reaches the earth from the fixed stars. Hitherto the knowledge possessed by man of these immensely distant bodies has been almost confined to the fact that some of them, which observation shows to be united in systems, are composed of matter subjected to the same laws of gravitation as those which rule the members of the solar system. To this may be added the high probability that they must be self-luminous bodies analogous to our sun, and probably in some cases even transcending it in brilliancy. Were they not self-luminous, it would be impossible for their light to reach us from the enormous distances at which, the absence of sensible parallax in the case of most of them shows, they must be placed from our system.

The investigation of the nature of the fixed stars by a prismatic analysis of the light which comes to us from them, however, is surrounded with no ordinary difficulties. The light of the bright stars, even when concentrated by an object-glass or speculum, is found to become feeble when subjected to the large amount of dispersion which is necessary to give certainty and value to the comparison of the dark lines of the stellar spectra with the bright lines of terrestrial matter. Another difficulty, greater because it is in its effect upon observation more injurious, and is altogether beyond the control of the experimentalist, presents itself in the ever-changing want of homogeneity of the earth's atmosphere, through which the stellar light has to pass. This source of difficulty presses very heavily upon observers who have to work in a climate so unfavourable in this respect as our own. On any but the finest nights the numerous and closely approximated fine lines of the stellar spectra are seen so fitfully that no observations of value

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can be made. It is from this cause especially that we have found the inquiry, in which for more than two years and a quarter we have been engaged, more than usually toilsome; and indeed it has demanded a sacrifice of time very great when compared with the amount of information which we have been enabled to obtain.

2. Previously to January 1862, in which month we commenced these experiments, no results of any investigation undertaken with a similar purpose had been published. With other objects in view, two observers had described the spectra of a few of the brighter stars, viz. FRAUNHOFER in 1823*, and DONATI, whose memoir, "Intorno alle strie degli spettri stellari," was published in the Annali del Museo Fiorentino for 1862.

FRAUNHOFER recognized the solar lines D, E, *b*, and F in the spectra of the Moon, Venus, and Mars; he also found the line D in Capella, Betelgeux, Procyon, and Pollux; in the two former he also mentions the presence of *b*. Castor and Sirius exhibited other lines. DONATI'S elaborate paper contains observations upon fifteen stars; but in no case has he given the positions of more than three or four bars, and the positions which he ascribes to the lines of the different spectra relatively to the solar spectrum do not accord with the results obtained either by FRAUNHOFER or by ourselves. As might have been anticipated from his well-known accuracy, we have not found any error in the positions of the lines indicated by FRAUNHOFER.

3. Early in 1862 we had succeeded in arranging a form of apparatus in which a few of the stronger lines in some of the brighter stars could be seen. The remeasuring of those already described by FRAUNHOFER and DONATI, and even the determining the positions of a few similar lines in other stars, however, would have been of little value for our special object, which was to ascertain, if possible, the constituent elements of the different stars. We therefore devoted considerable time and attention to the perfecting of an apparatus which should possess sufficient dispersive and defining power to resolve such lines as D and *b* of the solar spectrum. Such an instrument would bring out the finer lines of the spectra of the stars, if in this respect they resembled the sun. It was necessary for our purpose that the apparatus should further be adapted to give accurate measures of the lines which should be observed, and that it should also be so constructed as to permit the spectra of the chemical elements to be observed in the instrument simultaneously with the spectra of the stars. In addition to this, it was needful that these two spectra should occupy such a position relatively to each other, as to enable the observer to determine with certainty the coincidence or non-coincidence of the bright lines of the elements with the dark lines in the light from the star.

Before the end of the year 1862 we had succeeded in constructing an apparatus which fulfilled part of these conditions. With this some of the lines of the spectra of Aldebaran, α Orionis, and Sirius were measured; and from these measures diagrams of these stars, in greater detail than had then been published, were laid before the Royal Society in February 1863. After the note was sent to the Society, we became acquainted with some similar observations on several other stars by RUTHERFURD, in SILLIMAN'S Journal

* GILBERT'S 'Annalen,' vol. lxxiv. p. 374.

for 1863*. About the same time figures of a few stellar spectra were also published by SECCHI†. In March 1863, the Astronomer Royal presented a diagram to the Royal Astronomical Society, in which are shown the positions of a few lines in sixteen stars‡.

Since the date at which our note was sent to the Royal Society our apparatus has been much improved, and in its present form of construction it fulfils satisfactorily several of the conditions required.

§ II. *Description of the Apparatus and Methods of Observation employed.*

4. This specially constructed spectrum apparatus is attached to the eye end of a refracting telescope of 8 inches aperture and 10 feet focal length, which is mounted equatorially in the observatory of Mr. HUGGINS at Upper Tulse Hill. The object-glass is a very fine one, by ALVAN CLARK of Cambridge, Massachusetts; the equatorial mounting is by COOKE of York; and the telescope is carried very smoothly by a clock motion.

As the linear spectrum of the point of light which a star forms at the focus of the object-glass is too narrow for the observation of the dark lines, it becomes necessary to spread out the image of the star; and to prevent loss of light, it is of importance that this enlargement should be in one direction only; so that the whole of the light received by the object-glass should be concentrated into a fine line of light as narrow as possible, and having a length not greater than will correspond to the breadth of the spectrum (when viewed in the apparatus) just sufficient to enable the eye to distinguish with ease the dark lines by which it may be crossed. No arrangement tried by us has been found more suitable to effect this enlargement in one direction than a cylindrical lens, which was first employed for this purpose by FRAUNHOFER. In the apparatus by which the spectra described in our "Note" of February 1863 were observed, the cylindrical lens employed was plano-convex, of 0·5 inch focal length. This was placed within the focus of the object-glass and immediately in front of the slit of the collimator.

The present form of the apparatus is represented in Plate X. figs. 1 & 2, where the cylindrical lens is marked *a*. This is plano-convex, an inch square, and of about 14 inches focal length. The lens is mounted in an inner tube, *b*, sliding within the tube *c*, by which the apparatus is adapted to the eye end of the telescope. The axial direction of the cylindrical surface is placed at *right angles* to the slit *d*, and the distance of the lens from the slit within the converging pencils from the object-glass is such as to give exactly the necessary breadth to the spectrum.

In consequence of the object-glass being over-corrected, the red and, especially, the violet pencils are less spread out than the pencils of intermediate refrangibility; so that the spectrum, instead of having a uniform breadth, becomes slightly narrower at the red end, and tapers off in a greater degree towards the more refrangible extremity§.

* Vol. xxxv. p. 71. † Astronomische Nachrichten, No. 1405, March 3, 1863.

‡ Monthly Notices, Roy. Astron. Soc. vol. xxiii. p. 190.

§ The experiment was made of so placing the cylindrical lens that the axial direction of its convex cylin-

In front of the slit *d*, and over one half of it, is placed a right-angled prism *e*, for the purpose of reflecting the light which it receives from the mirror *f* through the slit. In the brass tube *c* are two holes: by one of these the light is allowed to pass from the mirror to the reflecting-prism *e*; and by means of the other, access to the milled head for regulating the width of the slit is permitted. Behind the slit, and at a distance equal to its focal length, is placed an achromatic collimating lens *g*, made by T. Ross; this has a diameter of 0·6 inch and a focal length of $4\frac{1}{2}$ inches. These proportions are such that the lens receives the whole of the light which diverges from the linear image of the star when this is brought exactly within the jaws of the slit.

The dispersing portion of the apparatus consists of two prisms, *h*, each having a refracting angle of about 60°; they were made by T. Ross, and are of very dense and homogeneous flint glass. The prisms are supported upon a suitable mounting, which permits them to be duly levelled and adjusted. Since the feebleness of the light from the stars limits the observations for the most part to the central and more luminous portions of the spectrum, the prisms have been adjusted to the angle of minimum deviation for the ray D. A cover of brass, *k*, encloses this part of the apparatus; and by this means the prisms are protected from accidental displacement, and from dust.

The spectrum is viewed through a small achromatic telescope *l*, furnished with an object-glass of 0·8 inch diameter and 6·75 inches focal length. This telescope has an adjustment for level at *m*. The axis of the telescope can be lowered and raised, and the tube can be also rotated around the vertical axis of support at *n*. At the focus of the object-glass are fixed two wires, crossing at an angle of 90°. These are viewed, together with the spectrum, by a positive eyepiece *p*, giving a magnifying power of 5·7 diameters. As the eyes of the two observers do not possess the same focal distance, a spectacle-lens, corresponding to the focal difference between the two, was fitted into a brass tube, which slipped easily over the eyepiece of the telescope, and was used or withdrawn as was necessary.

This telescope, when properly adjusted and clamped, is carried by a micrometer-screw *q*, which was constructed and fitted to the instrument by Cooke and Sons. The centre of motion about which it is carried is placed approximatively at the point of intersection of the red and the violet pencils from the last prism; consequently it falls within

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drical surface should be *parallel* with the direction of the slit. The line of light is in this case formed by the lens; and the length of this line, corresponding to the visible breadth of the spectrum, is equal to the diameter of the cone of rays from the object-glass where they fall upon the slit. With this arrangement, the spectrum appears to be spread out, in place of being contracted at the two extremities. Owing to the large amount of dispersion to which the light is subjected, it was judged unadvisable to weaken still further the already feeble illumination of the extremities of the spectrum; and in the examination of the stellar spectra the position of the cylindrical lens with its axis at right angles to the slit, as mentioned in the text, was therefore adopted.

A *plano-concave* cylindrical lens of about 14 inches negative focal length was also tried. The slight advantage which this possesses over the convex form is more than balanced by the inconvenience of the increased length given to the whole apparatus.

the last face of the prism nearest the small telescope. All the pencils therefore which emerge from the prism are, by the motion of the telescope, caused to fall nearly centrically upon its object-glass. The micrometer screw has 50 threads to an inch; and each revolution is read to the hundredth part, by the divisions engraved upon the head. This gives a scale of about 1800 parts to the interval between the lines A and H of the solar spectrum. During the whole of the observations the same part of the screw has been used; and the measures being relative, the inequalities, if any, in the thread of this part of the screw do not affect the accuracy of the results. The eye lens for reading the divisions of the micrometer-screw is shown at *s*.

The mirror *f* receives the light to be compared with that of the star-spectrum, and reflects it upon the prism *e*, in front of the slit *d*. This light was usually obtained from the induction spark taken between electrodes of different metals, fragments or wires of which were held by a pair of small forceps attached to the insulating ebonite clamp *r*. Upon a moveable stand in the observatory was placed the induction coil, already described by one of us*, in the secondary circuit of which was inserted a Leyden jar, having 140 square inches of tinfoil upon each of its surfaces. The exciting battery, which, for the convenience of being always available, consisted of four cells of SMEE'S construction, with plates 6 inches by 3, was placed without the observatory. Wires, in connexion with this and the coil, were so arranged that the observer could make and break contact at pleasure without removing his eye from the small telescope. This was the more important since, by tilting the mirror *f*, it is possible, within narrow limits, to alter the position of the spectrum of the metal relatively to that of the star. An arrangement is thus obtained which enables the observer to be assured of the perfect correspondence in relative position in the instrument of the stellar spectrum and the spectrum to be compared with it.

5. The satisfactory performance of this apparatus is proved by the very considerable dispersion and admirably sharp definition of the known lines in the spectra of the sun and metallic vapours. When it is directed to the sun, the line D is sufficiently divided to permit the line within it, marked in KIRCHHOFF'S map as coincident with nickel, to be seen. The close groups of the metallic spectra are also well resolved.

When this improved apparatus was directed to the stars, a large number of fine lines was observed, in addition to those that had been previously seen. In the spectra of all the brighter stars which we have examined, the dark lines appear to be as fine and as numerous as they are in the solar spectrum. The great breadth of the lines in the green and more refrangible parts of Sirius and some other stars, as seen in the less perfect form of apparatus which was first employed, and which band-like appearance was so marked as specially to distinguish them, has, to a very great extent, disappeared; and though these lines are still strong, they now appear, as compared with the strongest of the solar lines, by no means so abnormally broad as to require these stars to be placed in a class apart. No stars sufficiently bright to give a spectrum have been observed to

* Philosophical Transactions, 1864, p. 141.

be without lines. The stars admit of no such broad distinctions of classification. Star differs from star alone in the grouping and arrangement of the numerous fine lines by which their spectra are crossed.

6. For the convenience of reference and comparison, a few of the more characteristic lines of twenty-nine of the elements were measured with the instrument. These were laid down to scale, in order to serve as a chart, for the purpose of suggesting, by a comparison with the lines measured in the star, those elements the coincidence of the lines of which with stellar lines was probable.

For the purpose of ensuring perfect accuracy in relative position in the instrument between the star-spectrum and the spectrum to be observed simultaneously with it, the following general method of observing was adopted:—The flame of a small lamp of alcohol, saturated with chloride of sodium, was placed centrally before the object-glass of the telescope, so as to furnish a sodium-spectrum. The sodium-spectrum was then obtained by the induction spark, and the mirror f was so adjusted that the components of the double line D, which is well divided in the instrument, should be severally coincident in the two spectra. The lamp was then removed, and the telescope directed to the sun, when FRAUNHOFER'S line D was satisfactorily observed to coincide perfectly with that of sodium in the induction-spark. Having thus ascertained that the sodium lines coincided in the instrument with the solar lines D, it was of importance to have assurance from experiment that the other parts of the solar spectrum would also accurately agree in position with those corresponding to them in the spectrum of comparison. When electrodes of magnesium were employed, the components of the triple group characteristic of this metal severally coincided with the corresponding lines of the group *b*. C and F also agreed exactly in position with the lines of hydrogen; the coincidence of several of the principal lines of iron was also observed. The stronger of the FRAUNHOFER lines were measured in the spectra of the moon and of Venus, and these measures were found to be accordant with those of the same lines taken in the solar spectrum.

Before commencing the examination of the spectrum of a star, the alcohol-lamp was again placed before the object-glass of the telescope, and the correct adjustment of the apparatus obtained with certainty. The first observation was whether the star contained a double line coincident with the sodium line D. When the presence of such a line had been satisfactorily determined, we considered it sufficient in subsequent observations of the same star to commence by ascertaining the exact agreement in position of this known stellar line with the sodium line D.

Since from flexure of the parts of the spectrum apparatus the absolute reading of the micrometer might vary when the telescope was directed to stars differing greatly in altitude, the measure of the line in the star which was known to be coincident with that of sodium was always taken at the commencement and at the end of each set of measures. The distances of the other lines from this line, and not the readings of the micrometer, were then finally registered as the measures of their position; and these form the numbers given in the Tables, from which the diagrams of the star-spectra have been laid down.

The very close approximation*, not unfrequently the identity, of the measures obtained for the same line on different occasions, as well as the very exact agreement of the lines laid down from these measures with the stellar lines subsequently determined by a direct comparison with metallic lines the positions of which were known, have given the authors great confidence in the minute accuracy of the numbers and drawings which they have now the honour of laying before the Society.

§ III. *Observations on the Moon and Planets.*

7. It is well known that in the solar spectrum many additional remarkable lines make their appearance when light from the sun seen near the horizon reaches the observer, after having traversed a much greater length of our atmosphere than when the sun is viewed at greater altitudes. This circumstance suggested to us the importance of a careful examination of the solar light after reflexion from the moon and planets, in reference to the extent and analogous constitution of atmospheres possibly surrounding these bodies. As far as practicable, the spectra of the moon, Venus, Mars, Jupiter, and Saturn have been observed on several occasions with this special object in view.

8. *The Moon.*—All the astronomical phenomena in which we should expect to discover indications of an atmosphere about the moon, if such exist, agree in proving the non-existence of a lunar atmosphere of sensible amount. From the absence of appreciable refraction at the moon's limb, and from the *sudden* extinction during a total lunar eclipse of stars of even the tenth and eleventh magnitude at the limb of the moon, "we are," writes Sir JOHN HERSCHEL, "entitled to conclude that no amount of appreciable vapour is suspended near the surface of the moon, and .... the non-existence of an atmosphere at the moon's edge having the 1980th part of the density of the earth's atmosphere"†.

As by direct observation we know that the solar light is reflected from the *surface* of the moon, the light which reaches the earth after having undergone this reflexion must have passed through a length of lunar atmosphere, if such exist, at least equal to double the height of such atmosphere above that surface of the moon which is visible to us. From some parts of the moon, when the whole or a large part of its illuminated surface is turned towards the earth, the length of the column of lunar atmosphere which the solar light would have to traverse would be considerably greater.

The examination of lunar light by the spectroscope, and the comparison of the light reflected from different portions of the moon's illuminated surface with each other by this method, would take place under conditions favourable to the detection of an atmosphere of considerable extent, if such exist.

The moon was examined by us on April 12 and November 26, 1862, March 31 and

* These measures, on repeated observation, seldom varied more than a single division of the scale, or $\frac{1}{1800}$th of the distance between A and H.

† Outlines of Astronomy, 7th edition, par. 431, p. 284. See also a paper by Professor CHALLIS in the Monthly Notices of the Roy. Astron. Soc., vol. xxiii. p. 254, June 1863.

December 31, 1863, March 15 and 19, and April 12, 1864. The solar lines were perfectly well seen, appearing exceedingly sharp and fine. The line D was well divided, and its components were observed to coincide with those of sodium. Coincidence of the magnesium group with the three lines forming *b* was also observed. The lunar spectrum is indeed full of fine lines, and they were well seen from B to about halfway between G and H. On all these occasions no other strong lines were observed than those which are visible in the solar spectrum when the sun has a considerable altitude.

Previously to the observations of March 15 and 19 and April 12, 1864, the apparatus was directed to the sun when near the horizon, and the relative positions and characteristic appearances of the atmospheric lines in the orange and red were carefully observed. These portions of the spectrum were closely scrutinized when the moon's light was afterwards examined; but no indication of similar lines could be detected. On each of the three evenings just mentioned successive portions of the moon's illuminated surface from the centre to the circumference were brought before the slit of the spectrum apparatus. The quantity of light from different parts was observed to be very different, but not the smallest change in the lines of the spectrum could be perceived, either in respect of relative intensity or the addition or disappearance of any lines*.

The result of this spectrum analysis of the light reflected by the moon is wholly negative as to the existence of any considerable lunar atmosphere†.

9. *The Planets Venus, Mars, Jupiter, and Saturn.*—The very sensible and rapidly changing appearances of the disk of Jupiter, other than those due to the rotation of the planet, present very strong evidence of the existence of a very considerable atmosphere about Jupiter. The same, though in a much less marked degree, is probably true of Saturn and Mars. In addition, the diminished brightness of the disk of Jupiter near the periphery supports the inference that an atmosphere exists about that planet.

The planet Jupiter was observed on April 12, 1862, and April 14 and May 1, 1863.

* [With the spectrum apparatus described at page 421, the spectra of particular and very limited regions of the moon's surface can be examined. The opening of the slit of the apparatus corresponding to a spectrum that can be separately observed is about $\frac{1}{300}$ inch $\times \frac{1}{100}$ inch. The image of the moon formed by the object-glass of the telescope has a diameter of 1·04 inch. Practically it is found that the light reflected from an area upon the surface of the moon of about one-third that of Tycho can be analyzed in the instrument.

The particular spot of the moon's surface under observation can be ascertained by means of the finder attached to the telescope. For this purpose, however, a special set of wires, accurately adjusted, and an eyepiece of considerable power are necessary. When the part of the moon's surface under observation presents marked inequalities of illumination, the spectra of these differently illuminated portions can be easily recognized by the differences in their comparative brightness. In these observations the cylindrical lens may be removed.—August 31, 1864.]

† [A remarkably favourable opportunity of observing the effect upon the solar spectrum of transmission through a very large extent of the earth's atmosphere presents itself on the occasion of an eclipse of the moon. We had made preparations to observe the copper-coloured light reflected from the moon during the eclipse of June 1, 1863. The small altitude of the moon on this occasion rendered the observation impossible, from the circumstance that the eye end of the telescope, increased in length by the spectrum apparatus, came too near the wall of the observatory.—August 31, 1864.]

The solar lines B, C, D, E, *b*, F, and G were seen, with numerous fine intermediate lines, and D, E, *b*, and F were measured; but no marked lines other than those usually present in the solar spectrum were detected.

[Since these observations were made, we have had a spectrum apparatus constructed by Mr. BROWNING, optician, of the Minories, which is similar in general arrangement to that already described, but possesses much less dispersive power. In this apparatus the cylindrical lens, the collimating lens, and the object-glass of the small telescope correspond exactly in diameter and in focal length with those of which a description has been given; but the eyepiece of the telescope is of less power, and has a magnifying power of about three diameters. A second eyepiece was occasionally used, magnifying nine diameters. Two prisms are employed; one has a refracting angle of 35°, the other a refracting angle of 45°.

With this apparatus, in the spectrum of Jupiter a strong line in the red is seen which is scarcely distinguishable with the more powerful instrument, and was from this cause overlooked in our earlier observations. The remarkable increase of visibility of this line is due to the much greater brilliancy of the spectrum in this apparatus; and this is much more than inversely proportional to the diminution of the dispersion, since, on account of the greatly reduced obliquity of incidence, the loss of light at the surfaces of the prisms by reflexion is much less. This saving of light in the spectrum apparatus is of very great importance in observations of the planetary spectra. The image of a planet in the telescope is not a point, but forms a disk of considerable magnitude relatively to the image of a star. Of this image, enlarged in one direction by the cylindrical lens, a very narrow section only, corresponding to the breadth of the slit, passes on through the collimating lens to the prisms; and this portion only of the total light collected by the object-glass becomes available to form the spectrum. On this account we have found the observations of the planets much more difficult than would be observations of stars possessing an equal apparent brilliancy.

This band of which we are now speaking in the spectrum of Jupiter occurs in a rather obscure part of the spectrum; moreover, by the instrument of greater dispersive power, it appears to be resolved into two or more lines, which are severally very faint, and are less visible than a single stronger line. The altitude of Jupiter being small (about 22° above the horizon) at the time of observation, it was of great importance to have satisfactory evidence that this band was not due to absorption by our atmosphere.

On June 16, 1864, the moon and Jupiter being near each other in the sky, the opportunity was seized to compare directly the moon's light with that of Jupiter under precisely similar conditions of atmosphere. The observations of this evening were decisive in showing that this band in the spectrum of Jupiter was due to a modification suffered by the solar light before reaching our atmosphere, and therefore due probably to absorption by the atmosphere of Jupiter.

On June 20, and on July 12 and 14, an observation still more crucial was obtained. The length of the opening of the slit is much greater than the diameter of the tele-

scopic image of Jupiter, even after elongation by the cylindrical lens. If, therefore, at the time of observation the light from the sky is sufficiently intense to form a visible spectrum, the spectrum of the sky is seen in the instrument together with the spectrum of Jupiter, and much exceeding it in breadth. When the period is so chosen that the degree of illumination of the sky is suitable in proportion to the intensity of the light of Jupiter, the solar lines and those due to our atmosphere are well seen in close contiguity with the lines in the spectrum of Jupiter, and occupying exactly similar relative positions. The sky-spectrum is seen under precisely similar conditions of altitude and of state of atmosphere. To the light of Jupiter under these circumstances of observation is added the light reflected from the small area of sky immediately between the observer and the planet. This light is, however, too faint in proportion to that of Jupiter to become a source of error. In the diagram, fig. 3, Plate X., the position of this band is shown relatively to the spectrum of the sky. The band at 914 of the scale appears to be coincident with, but *much stronger* than, a faint band in the sky-spectrum. This increase in the strength of the band is probably due to an absorptive action exerted by the atmosphere of the planet.

The bands at 882 and 1033 of the scale are less intense in the spectrum of Jupiter than in the spectrum of the light of the sky. This variation of intensity is probably due to the circumstance that the light from the southern sky, before it is reflected to the observer, on account of the position of the sun, which is then near the horizon, has had to traverse a very much larger amount, and a more dense portion, of our atmosphere than that traversed by the light received from Jupiter. It is in accordance with this explanation that these bands are also less intense in the spectrum of the moon when similarly compared with those of the sky.

Other lines less refrangible were perceived in the spectrum of Jupiter, but were not sufficiently distinct to be measured. The bands in the orange and the red to which we have referred, when examined in the spectrum apparatus of greater dispersive power, and with a much stronger illumination by directing the apparatus to the sun when near the horizon, are resolved into groups of lines. The stronger of these lines are represented in the upper spectrum of the diagram. The relative position of the band in the red due to lines of oxygen and nitrogen when the induction spark is taken in air, is shown below the spectrum of Jupiter. This band is in a small degree more refrangible than the strong band due to Jupiter.

If this band, at 914 of the scale, in Jupiter's spectrum consists of lines severally coincident with the lines composing the faint atmospheric band with which it appears to correspond in position, it would seem entitled to be regarded as an evidence of the similarity of Jupiter's atmosphere with our own, with respect at least to one of its constituents, or to one of the vapours diffused through it. The smaller intensity of the bands 882 and 1033 would appear to oppose the supposition that Jupiter's atmosphere is identical with our own. This negative evidence, however, cannot be regarded as of much weight, since telescopic observations show that the light which we receive from

Jupiter is for the most part reflected from clouds floating in its atmosphere at an elevation above the planetary surface. The solar light, therefore, would not traverse the lower and denser portions of Jupiter's atmosphere, corresponding to those of our own atmosphere in which the vapours, which probably produce these lines, appear to be chiefly present. The band about C, and that a little more refrangible at 838 of the scale, appear quite as strong in Jupiter as in the light from the sky. It may therefore be supposed that these bands are in part due to absorption at Jupiter, since the light from Jupiter suffers less absorption from our atmosphere than does the solar light reflected from the sky under the circumstances in which the observations were made.

With the exception of these bands in the orange and the red, the spectrum of Jupiter appeared to correspond exactly with that of the sky.—August 31, 1864.]

Saturn was observed on April 12, 1862, April 14, 1863, and April 12, 1864. Several solar lines were seen, but the spectrum was too faint to permit of any satisfactory determination as to the presence or absence of atmospheric lines.

[The spectrum of Saturn was observed with the apparatus and in the manner described when speaking of Jupiter, on June 13, 16, and 20. The spectrum was more difficult of observation, on account of the feebler brilliancy of Saturn, and its less favourable position. Bands in the red and orange were seen similar to those in the spectrum of Jupiter, and by measurement these bands were found to occupy positions in the spectrum corresponding to those of the bands of Jupiter.—August 31, 1864.]

The spectrum of Mars was observed on November 6, 1862, and April 17, 1863. The principal solar lines were seen, and no other strong lines were noticed.

[On August 10 and 29, 1864, we re-examined Mars, using the new spectrum apparatus. No lines in the red, similar to those of Jupiter and Saturn, were observed; but in the extreme red, probably about B and α, two or three strong lines were seen. With the exception of these, no lines were detected in the red, orange, yellow, and green portions of the spectrum, other than those of the solar spectrum. At about F the brilliancy of the spectrum diminishes in a remarkable manner, in consequence of a series of strong and nearly equidistant bands, which commences at F and continues towards the more refrangible end as far as the spectrum can be traced. The absorption of these bands is evidently the cause of the predominance of the red rays in the light of this planet.

The spectrum apparatus of greater power resolves these bands in the blue into groups of lines.—August 31, 1864.]

The light of Venus gives a spectrum of great beauty. The observations were chiefly made on April 17, 22, and 26, 1863. The line D was seen double. B, C, and numerous solar lines to a little distance beyond G, were distinctly visible; and the principal of these were measured and found to agree with corresponding lines in the solar spectrum. Lines other than these, and in the position in which the stronger atmospheric lines present themselves, were carefully looked for, but no satisfactory evidence of any such lines has been obtained. Venus was observed as early in the evening as possible, and while a considerable amount of daylight still remained.

The imperfect evidence which analysis by the prism affords of the existence of atmospheres around these planets, notwithstanding the high probability, amounting almost to certainty in the case of Jupiter, that such atmospheres do exist, may receive an explanation in the supposition that the light is chiefly reflected, not from the planetary surfaces, but from masses of cloud in the upper strata of their atmospheres. In this case the length of atmosphere which the light would have to traverse would be considerably lessened. With perhaps the exception of Mars, telescopic observations are in favour of such a supposition.

§ IV. *Observations on the Fixed Stars.*

10. The number of fixed stars which we have, to a greater or less extent, examined amounts to nearly 50. We have, however, concentrated our efforts upon three or four of the brighter stars, and two only of these have been mapped with any degree of completeness. These spectra are, indeed, as rich in lines as that of the sun, and even with these it may be advantageous to compare the spectra of additional metals when the season is again favourable. The few really fine nights that are available whilst the star is well situated for such observations, in respect of altitude and the time of sun-setting, necessarily make the *complete* investigation even of a single star the work of some years.

11. ALDEBARAN (α Tauri) (Plate XI.).—The light of this star is of a pale red. When viewed in the spectroscope, numerous strong lines are at once evident, particularly in the orange, the green, and the blue portions. The positions of about seventy of these lines have been measured, and their places have been given in the Table. Besides these, numerous other strong lines are visible, particularly in the blue, but they have not been measured, owing to the feebleness of the light; we have therefore not inserted them in the Table or in the diagram. A similar remark is applicable also to the results of our examination of α Orionis and β Pegasi.

We have compared the spectra of sixteen of the terrestrial elements by simultaneous observation with the spectrum of Aldebaran, of course selecting those in which we had reason, from the observations, to believe coincidence was most likely to occur. Nine of these spectra exhibited lines coincident with certain lines in the spectrum of the star. They are as follows:—sodium, magnesium, hydrogen, calcium, iron, bismuth, tellurium, antimony, and mercury.

(1) *Sodium.*—The double line at D was coincident with a double line in the stellar spectrum.

(2) *Magnesium.*—The three components of the group at *b*, from electrodes of the metal, were coincident with three lines in the star-spectrum.

(3) *Hydrogen.*—The line in the red corresponding to C, and the line in the green corresponding to F in the solar spectrum, were coincident with strong lines in the spectrum of Aldebaran.

(4) *Calcium.*—Electrodes of the metal were used; four lines in its spectrum were observed to coincide with four of the stellar lines.

(5) *Iron.*—The lines in the spectrum of this metal are very numerous, but not remarkable for intensity. There was a double line corresponding to E in the solar spectrum, and three other more refrangible well-marked lines coincident with lines in the star.

(6) *Bismuth.*—Four strong lines in the spectrum of this metal coincided with four in the star-spectrum.

(7) *Tellurium.*—In the spectrum of this metal also four of the strongest lines coincided with four in the spectrum of the star.

(8) *Antimony.*—Three of the lines in the spectrum of antimony were observed to coincide with stellar lines.

(9) *Mercury.*—Four of the brightest lines in the mercury-spectrum correspond in position with four lines of the star.

It must not be supposed that other lines in all the spectra of the elements above enumerated do not possess corresponding lines in the star-spectrum. Comparisons of this kind are extremely fatiguing to the eye, and are necessarily limited to the stronger lines of each spectrum. In no case, in the instances above enumerated, did we find any strong line in the metallic spectrum wanting in the star-spectrum, in those parts where the comparison could be satisfactorily instituted.

Seven other elements were compared with this star, viz. nitrogen, cobalt, tin, lead, cadmium, lithium, and barium. No coincidence was observed. With *nitrogen* three strong double lines were compared, with *cobalt* one strong single line and a double line, with *tin* five lines, with *lead* two strong lines, with *cadmium* three lines, with *barium* two of the strongest in the green, and with *lithium* the line in the orange, but were found to be without any strong lines in the star-spectrum corresponding with them. The positions of these several lines relatively to the star-spectrum are given in the diagram.

12. α Orionis (Betelgeux) (Plate XI.).—The light of this star has a decided orange tinge. None of the stars which we have examined exhibits a more complex or remarkable spectrum than this. Strong groups of lines are visible, especially in the red, the green, and the blue portions. In the blue comparatively few of these lines have been measured with accuracy; we have therefore not inserted them in the Table or the diagram. We have measured the position of about eighty lines in the brighter portions of this spectrum.

In the interval between the divisions 890 and 920 of the scale adopted in the diagram, is a shading as of fine lines. A fainter shading of the same character is observed between 990 and 1010, also from 1050 to 1069. A stronger similar shading occurs from 1145 to 1170, and from 1280 to 1300. A similar shaded band commences at 1420, and another at 1557.

The spectra obtained from sixteen elementary bodies were observed simultaneously with the spectrum of α Orionis. In five of these, viz. sodium, magnesium, calcium, iron, and bismuth, lines corresponding with certain stellar lines were found to exist.

(1) *Sodium.*—The lines coincident with D are fainter in this star than in Aldebaran.

(2) *Magnesium.*—Decided group of three stellar lines coincident with the group at *b*.

(3) *Calcium.*—Four lines of this metal were on two different occasions seen to be coincident with four lines in the spectrum of the star.

(4) *Iron.*—The double line of this metal at E, and three other more refrangible bright lines, coincide with lines in the star-spectrum.

(5) *Bismuth.*—In the spectrum of this metal also four lines were found to coincide with four in the stellar spectrum.

Thallium.—The bright green line so characteristic of this metal appears to coincide with one of the lines seen in the star-spectrum; but this line may be due to calcium, since the small difference between the position of the thallium line and that of one of the calcium lines very close to it would not be distinguishable with the dispersive power of the apparatus employed.

In the spectra of the other elements which we compared with that of the star, no coincidences occur.

Hydrogen.—There is no line coincident with the red line C of hydrogen; but in the star are two strong lines, one on either side of the position of C: there is also no line coincident with F. It is strikingly confirmatory of this method of analysis, that in all the stars hitherto examined by us in which a line corresponding to C exists, that corresponding to F is also found. When F is absent, C is also wanting.

In *nitrogen* three strong double lines were compared. In *tin* five lines, and in *lead* two bright lines were compared, but no coincidence was found.

Gold.—The strongest of the gold lines approximates closely in position to one in the spectrum of the star, but it is probably not coincident.

Three of the strong lines of *cadmium*, two of *silver*, four of *mercury*, two of *barium*, and one (the orange line) of *lithium* were observed to be not coincident with any of the lines visible in the star. In these comparisons, when barium was used, it was employed in the form of a nearly solid amalgam.

The opening of the slit was maintained at the same width (not more than the $\frac{1}{500}$th of an inch) for all the observations, both with Aldebaran and α Orionis. In the case of the fainter star which follows, it was very slightly widened.

13. β Pegasi.—The colour of this star is a fine yellow. In the general arrangement of the groups, in the gradation of the strength of the lines composing the groups, and in the absence of the hydrogen lines, this spectrum, though much fainter, is closely analogous with the spectrum of α Orionis, as figured in the Plate.

This star was carefully observed on many different occasions; but the faintness of the star, and the unfavourable state of the atmosphere on many of the nights of observation, did not permit the same number of lines to be measured, nor allow a comparison with an equal number of terrestrial elements. From November 10, 1862, when twelve lines were observed, to the present year, we have scrutinized the star carefully.

Nine of the elements were compared with the spectrum of β Pegasi. Two of these, viz. *sodium* and *magnesium*, and perhaps a third, viz. *barium*, furnish spectra in which there are lines which coincide with lines in the spectrum of the star.

The spectra of *iron* and *manganese* were also compared with that of the star, but the state of the atmosphere prevented any certain conclusion.

The lines in the spectra of *nitrogen*, *tin*, and *mercury* were not coincident with any definite lines in the star-spectrum. Neither of the *hydrogen* lines corresponding to C and F was present.

At the end of the paper we have given a Table of such measures of the lines in the spectrum of this star as we can depend upon. Although it appears to be as full of lines as either of the preceding stars, the observations are attended with great difficulty, owing to the insufficient amount of light.

The absence in the spectrum of α Orionis, and also in the spectrum of β Pegasi, which so closely resembles it in character, of lines corresponding to those of hydrogen, is an observation of considerable interest. It is of the more importance since the lines C and F are highly characteristic of the solar spectrum and of the spectra of by far the larger number of the fixed stars to which our observations have been extended.

These exceptions are further interesting as they seem to prove that the lines C and F are due to the luminous bodies themselves. Of this some doubt might be entertained, and it might be suspected that they are in some way due to our own atmosphere, if these lines were present in the spectra of *all* the stars without exception.

This absence of the lines corresponding to hydrogen is also the more entitled to consideration since it is so rare to find them wanting, amongst the considerable number of stellar spectra which we have observed.

14. Sirius.—The spectrum of this brilliant white star is very intense; but owing to its low altitude, even when most favourably situated, the observation of the finer lines is rendered very difficult by the motions of the earth's atmosphere. For the present we do not give any details of our measures. The lines in the green and blue appeared, in the less perfect form of spectroscope which we employed in the early part of 1863, of very great breadth, and were so figured in the diagram of the spectrum of this star given in our "Note" of February 1863. With our present instrument, possessing much greater dispersive power and a very narrow slit, these bands appear but little broader than F and G are at times seen in the solar spectrum. In February 1863, the breadth of the band corresponding to F measured $1\frac{1}{2}$ unit of the scale we then adopted; each unit corresponded to 15·5 units of our present scale. The micrometric measurement of this line in Sirius, in terms of our present scale, is only 3·7—that is, only about one-seventh of the breadth as seen with the wider slit and a dispersing arrangement having little more than one-third of the power of the present apparatus.

Three if not four elementary bodies have been found to furnish spectra in which lines coincide with those of Sirius, viz. sodium, magnesium, hydrogen, and probably iron.

(1) *Sodium.*—A double line in the star, though faint, coincides in position with the line of this metal.

(2) *Magnesium.*—Three lines in the star-spectrum coincide with the triple group of magnesium.

(3) *Hydrogen.*—Both the lines corresponding to F and C have intensely strong lines in the star-spectrum.

(4) *Iron.*—No direct comparison with this metal was made; but the cross wires having been set to a position corresponding with E of the solar spectrum, a faint line in the star was seen exactly to bisect the wires when the telescope was turned upon Sirius.

The whole spectrum of Sirius is crossed by a very large number of faint and fine lines.

It is worthy of notice that in the case of Sirius, and a large number of the white stars, at the same time that the hydrogen lines are abnormally strong as compared with the solar spectrum, all the metallic lines are remarkably faint.

On the 27th February, 1863, and on the 3rd of March of the same year, when the spectrum of this star was caused to fall upon a sensitive collodion surface, an intense spectrum of the more refrangible part was obtained. From want of accurate adjustment of the focus, or from the motion of the star not being exactly compensated by the clock movement, or from atmospheric tremors, the spectrum, though tolerably defined at the edges, presented no indications of lines. Our other investigations have hitherto prevented us from continuing these experiments further; but we have not abandoned our intention of pursuing them.

15. α Lyræ (Vega).—This is a white star having a spectrum of the same class as Sirius, and as full of fine lines as the solar spectrum. Many of these we have measured, but our investigation of this star is incomplete.

We have ascertained the existence, in the stellar spectrum, of a double line at D corresponding to the lines of *sodium*, of a triple line at *b* coinciding with the group of *magnesium*, and of two strong lines coincident with the lines of *hydrogen* C and F.

16. Capella.—This is a white star with a spectrum closely resembling that of our sun. The lines are very numerous; we have measured more than twenty of them, and ascertained the existence of the double *sodium* line at D, but we defer giving details until we have completed our comparison with the spectra of other metals.

From this star we obtained (on February 27, 1863) a photograph of the more refrangible end of the spectrum; but the apparatus was not sufficiently perfect to exhibit any stellar lines.

17. Arcturus (α Boötis).—This is a red star the spectrum of which somewhat resembles that of the sun. In this also we have measured upwards of thirty lines, and have ascertained the existence of a double *sodium* line at D; but our comparisons with other metallic spectra are not yet complete.

18. Pollux.—In the spectrum of this star, which is rich in lines, we have measured twelve or fourteen, and have observed coincidences with the lines of *sodium*, *magnesium*, and probably of *iron*. At any rate there is a line which we believe occupies the position of E in the solar spectrum.

α Cygni and Procyon are both full of fine lines. In each of these spectra we observed a double line coincident with the *sodium* D.

19. The following stars have also been observed: numerous lines are seen in the spectrum of each; and in some, several of the lines were measured; but we have not instituted any comparisons with the metallic spectra as yet.

Castor; ε, ζ, and η *Ursæ majoris*; α and ε *Pegasi*; α, β, and γ *Andromedæ*, the last an interesting spectrum; *Rigel*, a spectrum full of fine lines; η *Orionis*; α *Trianguli*; γ and ε *Cygni*; α, β, γ, ε, and η *Cassiopeiæ*; γ *Geminorum*; β *Canis majoris*; β *Canis minoris*; *Spica*; γ, δ, and ε *Virginis*; α *Aquilæ*; *Cor Caroli*; β *Aurigæ*; *Regulus*; β, γ, δ, ε, ζ, and η *Leonis*.

§ V. *General Observations.*

20. *On the Colours of the Stars.*—From the earliest ages it has been remarked that certain of the stars, instead of appearing to be white, shine with special tints; and in countries where the atmosphere is less humid and hazy than our own, this contrast in the colour of the light of the stars is said to be much more striking. Various explanations of the contrast of colours, by SESTINI and others, founded chiefly on the difference of the wave-lengths corresponding to the different colours, have been attempted, but as yet without success. Probably in the constitution of the stars as revealed by spectrum analysis, we shall find the origin of the differences in the colour of stellar light*.

Since spectrum analysis shows that certain of the laws of terrestrial physics prevail in the sun and stars, there can be little doubt that the immediate source of solar and stellar light must be solid or liquid matter maintained in an intensely incandescent state, the result of an exceedingly high temperature. For it is from such a source alone that we can produce light even in a feeble degree comparable with that of the sun.

The light from incandescent solid and liquid bodies affords an unbroken spectrum containing rays of light of every refrangibility within the portion of the spectrum which is visible. As this condition of the light is connected with the state of solidity or liquidity, and not with the *chemical* nature of the body, it is highly probable that the light when first emitted from the photosphere, or light-giving surface of the sun and of the stars, would be in all cases identical.

The source of the difference of colour, therefore, is to be sought in the difference of the constituents of the investing atmospheres†. The atmosphere of each star must

* In connexion with this subject we quote the following passage from SMYTH's 'Speculum Hartwellianum,' 4to, 1860, p. 315:—"Sir DAVID BREWSTER observes that there can be no doubt that in the spectrum of every coloured star certain rays are wanting which exist in the solar spectrum; but we have no reason to believe that these defective rays are absorbed by any atmosphere through which they pass. And in recording the only observation perhaps yet made to analyze the light of the coloured stars, he says, 'In the orange-coloured star of the double star ζ Herculis, I have observed that there are several defective bands. By applying a fine rock-salt prism, with the largest possible refracting angle, to this orange star, as seen in Sir JAMES SOUTH's great achromatic refractor, its spectrum had the annexed appearance [in the Campden Hill Journal], clearly showing that there was one defective band in the red space, and two or more in the blue space. Hence the colour of the star was orange, because there was a greater defect of blue than of red rays.'"

† The presence in the atmospheres of Aldebaran and α Orionis of metals, such as iron, which require an

vary in nature as the constituents of the star vary; and observation has shown that the stars do differ from the sun and from each other in respect of the elements of which they consist. The light of each star therefore will be diminished by the loss of those rays which correspond in refrangibility to the bright lines which the constituents of each atmosphere would, in the incandescent state, be capable of emitting. In proportion as these dark lines preponderate in particular parts of the spectrum, so will the colours in which they occur be weaker, and consequently the colours of other refrangibilities will predominate.

Of this the spectrum of α Orionis affords a good example. The green and blue parts of the spectrum are comparatively dark, from the numerous and close groups of dark lines. In the orange they are less strong. Hence it might be anticipated that the light of the star would be characterized by "an orange tinge," as noted by SMYTH. β Pegasi is described by SMYTH as "deep yellow;" and the appearance exhibited by its spectrum, which closely resembles that of α Orionis, though much fainter, supports the same view.

Aldebaran is recorded by SMYTH as of a "pale rose tint." In the spectrum of this star, with the exception of the hydrogen line C, there are but few strong lines in the red, whilst the orange portion is considerably subdued by dark lines, which are less numerous in the green and blue. Sirius, on the contrary, is "brilliant white" (SMYTH); and the continuous brightness of the spectrum, with the exception of five strong lines, is, as compared with Aldebaran and α Orionis, unaffected by the dark lines which cross it. The spectrum is indeed crowded with numerous fine lines; but the intensity of these lines is extremely feeble as contrasted with those of the stars just mentioned. It may be that the length of the stellar atmosphere through which the light passes is less, relatively to the intensity of radiation from the photosphere, and so is insufficient to produce lines of the same degree of blackness as would be produced if the atmosphere were denser. The great intensity, however, of the light of Sirius would rather lead to the conclusion that the atmosphere of vapours is itself highly incandescent. If so, might it not to some extent replace with its own light, the light which it has absorbed from the photosphere behind it? It matters little, however, for the present purpose, whether or not either of these suppositions be adopted. There is at all events a most striking difference between the effect on the colour of the star of the closely grouped and very dark lines in the green and blue portions of the spectrum of α Orionis and of the corresponding portion of the spectrum of Sirius, in which the dark lines are faint and wholly unequal to produce any noticeable subduing of the blue and green rays.

We have not yet had an opportunity of testing by experiment whether this hypo-

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exceedingly high temperature to convert them into vapour, renders untenable the supposition, which might otherwise have been entertained, that the orange and red tints of the light of these stars might be due to an inferior degree of incandescence of the photosphere as compared with the temperature of the stars the light of which is white.

thesis of the origin of the colours of the light of the stars is also applicable to the remarkable exceptional class of stars the light of which is of a decided green, blue, or violet colour. Such stars are usually very small, and they are always so closely approximated to other more brilliant stars, that it is scarcely possible, with the apparatus which we employ, to obtain separate images of the two spectra: and even were such separation easily practicable, the light of the strongly coloured star is usually so feeble that its satisfactory prismatic analysis would be a matter of great difficulty.

[One of the objects proposed in the construction of the spectrum apparatus with which the additional observations on Jupiter, Saturn, and Mars were made, and which has been described (p. 421) in connexion with those observations, was to make it available for the prismatic observation of some double and multiple stars.

Before commencing the observation of the spectra of the components of a double star, it is necessary that the position-angle of the stars should be approximatively known. The spectrum apparatus has then to be rotated upon the end of the telescope until the direction of the slit becomes perpendicular to a line joining the stars. When the instrument is in this position, the images of the stars are elongated by the cylindrical lens into two short lines of light parallel with the slit, and separated from each other by a small interval. If the telescope be now moved in a direction at right angles to that of the slit, either of the elongated stellar images can, at pleasure, be made to fall upon the slit and form its spectrum in the instrument. By adopting this method of observation, the spectra of the components of β Cygni were separately examined. These spectra, especially that of B, are so faint that the lines are seen with difficulty, and scarcely admit of being measured. Since, however, on account of the strongly contrasted colours of these stars, considerable interest attaches to a comparative examination of their spectra, we have represented in fig. 4, Plate X., the appearances which these spectra present to the eye, though we have not yet measured the lines and bands in them. These figures must be regarded as eye-estimations only of the general features of the two spectra. The spectra contain, doubtless, many other lines; and the positions of the lines inserted in the drawings, with the exception of *b* and D, were not measured, but only roughly estimated. The distinctive characteristics of these spectra are in accordance with the theory of the origin of the colours of the stars proposed in the foregoing paragraphs. In the case of both stars, the portions of the spectrum which correspond to the colours which are deficient in the light of the star, are those which are most strongly shaded with bands of absorption. Thus in the spectrum of A, the light of which is yellow tinted with orange, the absorption is greatest in the violet and blue; for the strong lines in the orange and red, since they are narrow, would diminish in a much smaller degree the light of these refrangibilities. The yellow and part of the green are free from *strong* lines.

The light of the star B appears to us to be blue, though in some states of the atmosphere the star becomes greenish blue, green, and even greenish white. These changes are probably due to the comparatively greater absorptive action of the vapours in the

air upon the more refrangible portions of the spectrum; in proportion to which absorption the other parts of the spectrum become relatively exalted, and thus predominate more or less in the eye.

This inequality of the absorptive action of the vapours of the atmosphere upon different parts of the spectrum becomes very evident if the eyepiece of the telescope be put out of focus (without the focus) so as to bring the blue and red rays to a focus in the centre of an expanded image of the star. In the case of B of β Cygni, the centre appears purple, surrounded with a margin of green. In proportion to the changes in the atmosphere by the passage of masses of vapour or thin cloud, will be the variations of these colours. The green becomes greener; but the blue and the violet are affected in a much greater degree, at times fading almost completely; then the colours resume their former tints and brightness. Several such changes may sometimes occur during one observation.

The spectrum B observed under conditions of atmosphere in which the colour of the star was blue, was remarkable for the faintness of the orange and yellow portions compared with the rest of the spectrum. The diminished brightness of these parts appears to be produced by several groups of closely set fine lines, while towards the more refrangible limit of the spectrum a few strong lines separated by considerable intervals are seen.

The observation of this star, on account of the faintness of its spectrum, is so difficult and fatiguing to the eye that we have not been able to examine it more accurately or in greater detail.

We have by the same method of observation examined the spectra of the components of α Herculis. The spectrum of A is remarkable for the great strength of the groups of lines in the green, blue, and violet; fainter bands are visible in the yellow and orange, also two strong bands in the red. This arrangement of the bands of absorption agrees with the orange colour which strongly predominates in the light of this star.

B is bluish green in colour. The more refrangible portions of its spectrum are very bright in consequence of the absence of any strong bands. The yellow and the orange parts are crossed by several groups of lines.—August 31, 1864.]

The suggestive fact that stars of these more highly refrangible colours are always observed in close contiguity with much brighter stars, generally of an orange or red tint, would afford countenance to the supposition that these exceptional colours are due to some special physical conditions essentially connected with the stellar systems of which they seem to form a part.

Arago* remarks, "Among the sixty or eighty thousand *isolated* stars, the positions of which are to be found in the catalogues of astronomers, there are none, I think, inscribed with any other indications in regard to colour, than white, red, and yellow. The physical conditions which determine the emission of blue and green light appear, then, to exist only in *multiple* stars."

* Popular Astronomy, translated by Smyth and Grant, vol. i. p. 295.

These stars are without exception feeble in the intensity of their light. The explanation is not admissible, that the faint blue or violet light is due to a less intense incandescence of the radiating surface, since it is precisely these more refrangible rays which would be the first to fail as the temperature diminished, and upon this supposition the star should be dull red. It is of course to be supposed that in the process of gradual cooling some bodies which are less volatile than others would cease to exist in the atmosphere at an earlier period than others, or that they might enter into new combinations more readily than others, and so modify the tint of the light emitted.

The existence around these blue stars of an extended atmosphere of "fog" will not explain the absorption of the *less* refrangible portion of the luminous spectrum.

21. These spectrum observations are not without interest also when viewed in connexion with the *nebular hypothesis* of the cosmical origin of the solar system and fixed stars. For if it be supposed that all the countless suns which are distributed through space, or at least those of them which are bright to us, were once existing in the condition of nebulous matter, it is obvious that, though certain constituents may have been diffused throughout its mass, yet the composition of the nebulous material must have differed at different points; otherwise, during the act of agglomeration, each system must have collected and condensed equal proportions of similar materials from the mass around. It cannot be supposed that similarity in physical properties has caused the association of the different elements: we find, for example, some of the least volatile of the metals, such as iron, associated with highly volatile elements, such as mercury and tellurium, in the same star.

If we may so say, there seems to be some analogy between this irregular distribution of the elements in different centres in space, and the manner in which the components of the earth's crust are distributed. Upon the earth there are certain very generally diffused elements, such as oxygen, hydrogen, carbon, silicon, iron, aluminium, and calcium, which occur in all parts; whilst there are others which, like silver, tin, lead, and other metals, are accumulated at particular points only. Whatever may have been the physical causes which may have produced this separation, we see abundant evidence of the advantage of this distribution in their application to the purposes of man—smallness in relative amount being compensated for by the accumulation of the material in denser deposits, which allow of their comparatively easy extraction to supply the wants of mankind. If this arrangement be admitted as designed in the case of the earth, is it going beyond the limits of fair deduction to suppose that, were we acquainted with the economy of those distant globes, an equally obvious purpose might be assigned for the differences in composition which they exhibit?

22. The additional knowledge which these spectrum observations give us of the nature and of the structure of the fixed stars, seems to furnish a basis for some legitimate speculation in reference to the great plan of the visible universe, and to the special object and design of those numerous and immensely distant orbs of light.

The closely marked connexion, in similarity of plan and mode of operation, in those

parts of the universe which lie within the range of experiment, and so of our more immediate knowledge, renders it not presumptuous to attempt to apply the process of reasoning from analogy to those parts of the universe which are more distant from us.

Upon the earth we find that the innumerable individual requirements which are connected with the present state of terrestrial activity, are not met by a plan of operation distinct for each, but are effected in connexion with the special modifications of a general method embracing a wide range of analogous phenomena. If we examine living beings, the persistence of unity of plan observable amidst the multiform varieties of special adaptation of the vertebrate form of life may be cited as an example of the unity of operation referred to. In like manner the remarkably wide range of phenomena which are shown to be reciprocally interdependent and correlative of each other, by the recent great extension of our knowledge in reference to the relation of the different varieties of force and their connexion with molecular motion, exhibits a similar unity of operation amidst the changes of the bodies which have not life.

The observations recorded in this paper seem to afford some proof that a similar unity of operation extends through the universe as far as light enables us to have cognizance of material objects. For we may infer that the stars, while differing the one from the other in the kinds of matter of which they consist, are all constructed upon the same plan as our sun, and are composed of matter identical, at least in part, with the materials of our system.

The differences which exist between the stars are of the *lower order*, of differences of *particular adaptation*, or special modification, and not differences of the *higher order* of distinct *plans of structure.*

There is therefore a probability that these stars, which are analogous to our sun in structure, fulfil an analogous purpose, and are, like our sun, surrounded by planets, which they by their attraction uphold, and by their radiation illuminate and energize. And if matter identical with that upon the earth exists in the stars, the same matter would also probably be present in the planets genetically connected with them, as is the case in our solar system.

It is remarkable that the elements most widely diffused through the host of stars are some of those most closely connected with the constitution of the living organisms of our globe, including hydrogen, sodium, magnesium, and iron. Of oxygen and nitrogen we could scarcely hope to have any decisive indications, since these bodies have spectra of different orders. These forms of elementary matter, when influenced by heat, light, and chemical force, all of which we have certain knowledge are radiated from the stars, afford some of the most important conditions which we know to be indispensable to the existence of living organisms such as those with which we are acquainted. On the whole we believe that the foregoing spectrum observations on the stars contribute something towards an experimental basis on which a conclusion, hitherto but a pure speculation, may rest, viz. that at least the brighter stars are, like our sun, upholding and energizing centres of systems of worlds adapted to be the abode of living beings.

Table of Stellar Spectra.

Aldebaran.

822·5	H	1107	
855·5		1112	Te
872·5		1117·5	Sb
880		1143 *d*	
893·5		1158	
900		1164	Hg
903·5		1171·5	
907·5		1178	
915		1187	
918	Ca	1192	
923	Hg	1202	
933	Ca	1210	
945·5	Sb	1224·5	
951·5		1240	
954·5		1241·5	
956		1250	
966·5	Sb	1252	Fe
972·5		1269·5	Fe
976	Te	1272	
982		1277	Bi
986·5		1282	
993		1291·5	Mg
1000	Na	1297·5	Mg
1002	Na	1300·5	Mg
1013	Ca	1314	Bi
1023		1323	
1028		1328	
1031		1351	
1036·5	Hg	1420	Fe
1040		1442·5	Fe
1044	Hg	1483	H
1058			
1062	Bi		
1067	Te		
1076			
1086·5	Te		
1095			
1100			
1105	Ca		

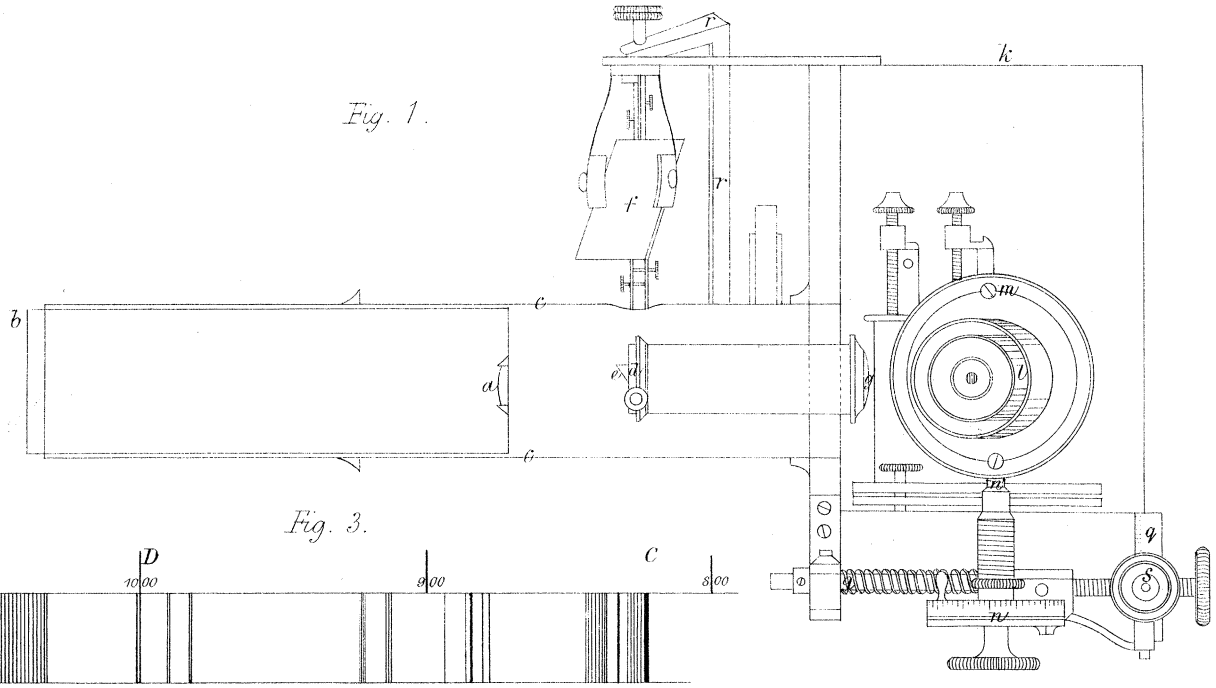
α Orionis.

840		1139·5	
860		1144	
870		1145.5	
881		1148	
887		1151	
890		1158·5	
899		1167	
911		1169·5	
918	Ca	1176·5	
920		1183·5	
929		1187	
933	Ca	1191·5	
936		1198	
946		1201·5	
966		1210	Te
968·5		1214	
976		1220·5	
983		1225	
992		1237	
1000	Na	1243	
1002	Na	1252	Fe
1010·5		1262	
1013	Ca	1269·5	Fe
1030		1277	Bi
1040		1280·5	
1050·5		1285·5	
1062	Bi	1291·5	Mg
1069·5		1297·5	Mg
1079·5		1300·5	Mg
1085·5		1303	
1090		1314	Bi
1091·5		1334	
1099		1350	
1105	Ca	1356	
1109·5		1361	
1116·5		1416	
1123·5		1420	Fe
1132		1442·5	Fe
1135·5		1557	

β Pegasi.

896		
923		
1000	Na	
1002	Na	
1014		
1165		
1220		
1276·5		
1291·5	Mg	
1297·5	Mg	
1300·5	Mg	
1350·5		
1392·5		
1425		
1515		
1732		
1835		

Fig. 1.



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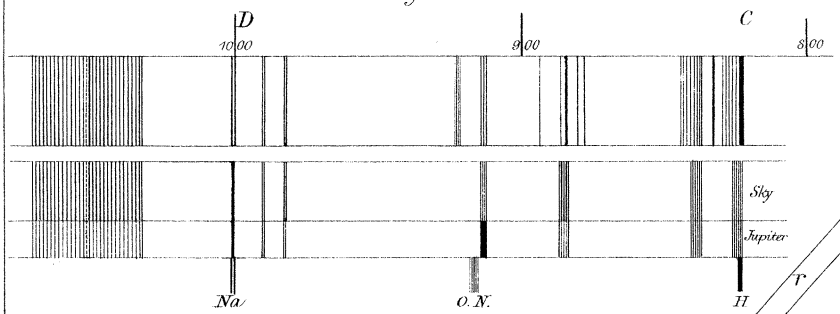

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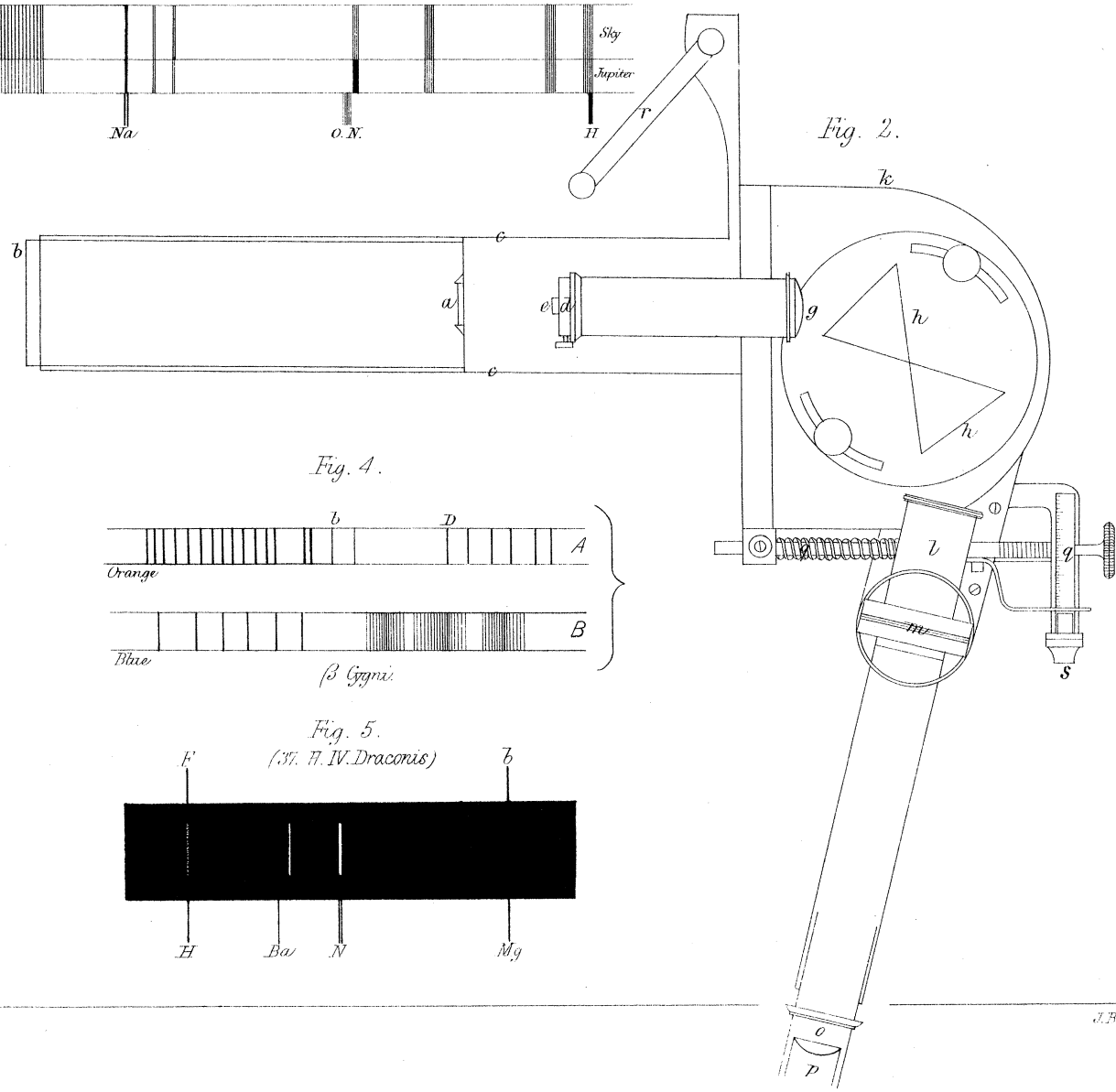


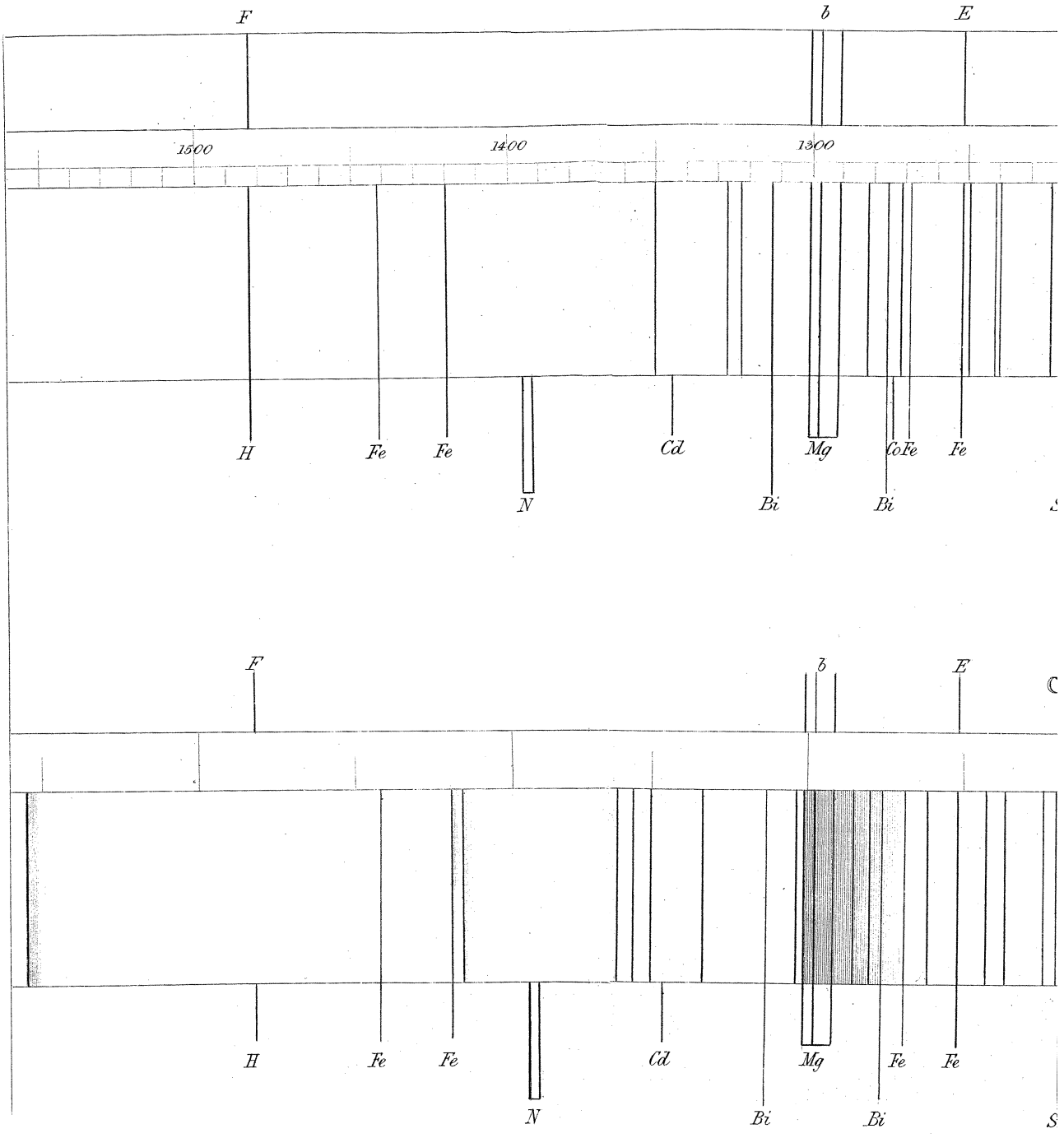
Fig. 4.

β Cygni.

Fig. 5.

(37. H. IV. Draconis)

J. Basire, lith.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1300
H
Fe
Fe
N
Cd
Bi
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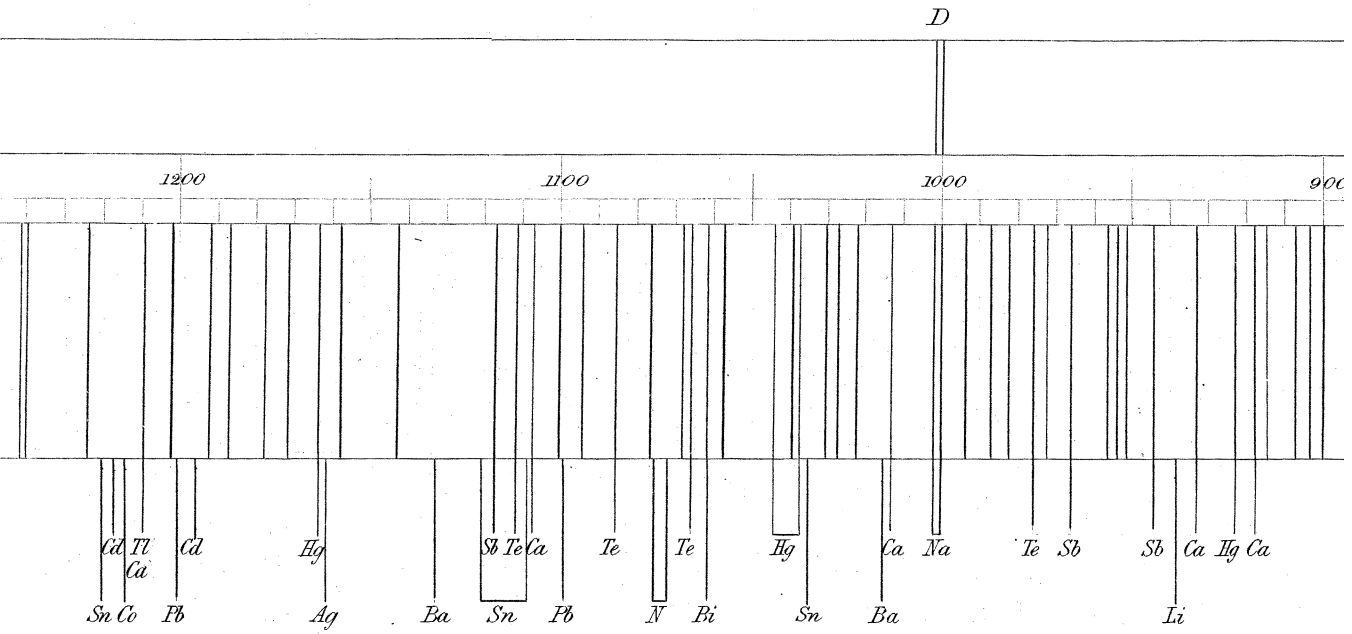
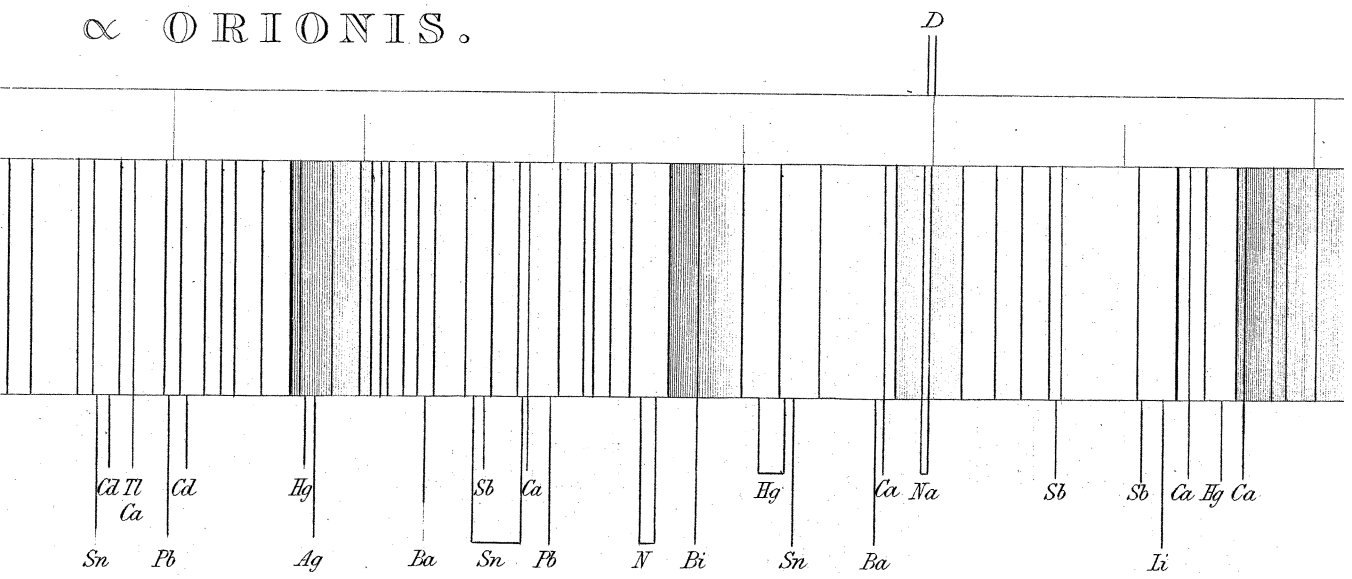
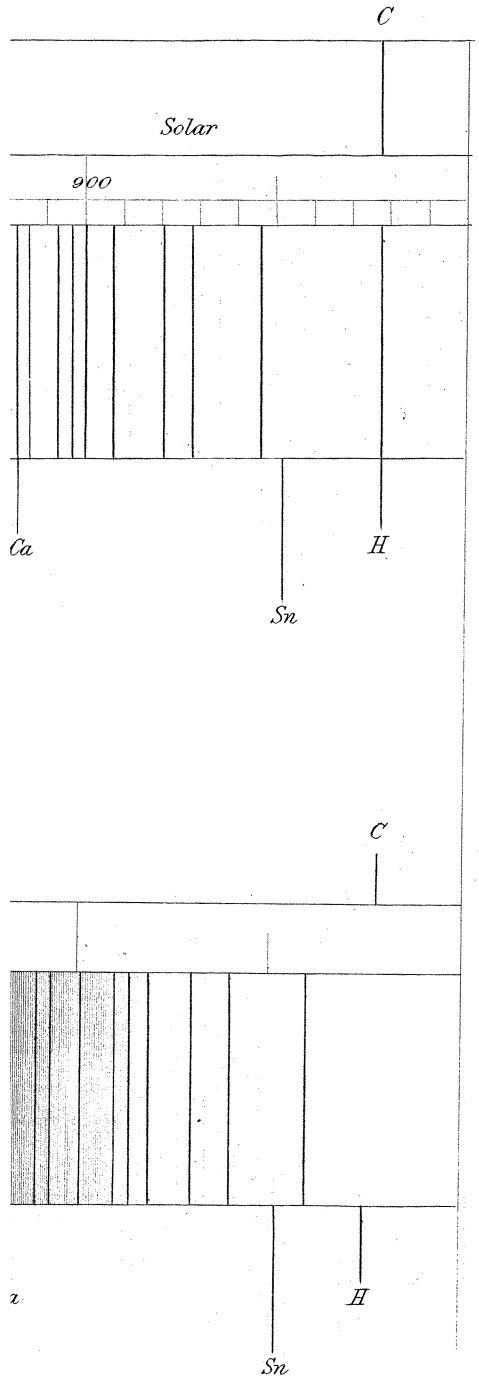
Cd
Bi
Mg
Fe
Bi
Fe

ALDEBARAN.

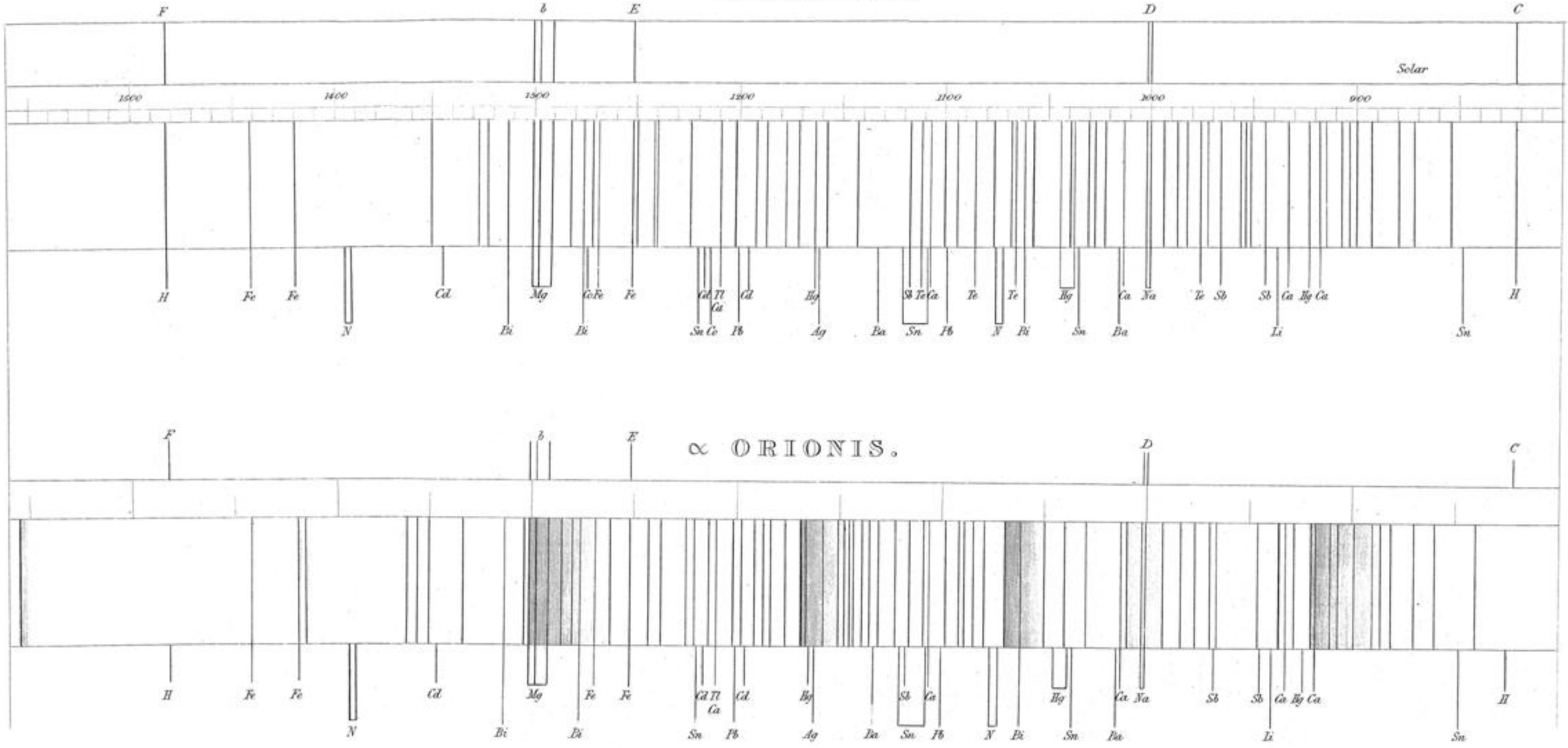


∝ ORIONIS.




C
Solar
900
Ca
H
Sn
C
a
H
Sn

ALDEBARAN.



∝ ORIONIS.

J. Basire sc.