

ART. VIII.—*Upon a new Spectroscope, with Contributions to the Spectral Analysis of the Stars*; by DR. J. C. F. ZÖLLNER.*

STELLAR spectrum analysis, in addition to its revelations concerning the physical constitution of the heavenly bodies, has begun most recently to claim attention in an increasing degree in another no less interesting direction. With the aid of this method the prospect is presented of proving, and under favorable circumstances also of measuring, what influence is exerted on the lines of the spectrum of a star by the components of the relative motion of the earth and star along the line uniting the two bodies.

A single consideration shows that effects which two separated bodies exert upon one another by means of a periodical impulse of a limited rapidity of propagation must be modified by a continual change of the distance separating them. It is Doppler's merit to have first, in the year 1841, recognized the necessity of this influence,† although the conclusions which he derived from it with respect to the color of the stars must be acknowledged as incorrect by reason of a disregard of the invisible parts of the spectrum.

With reference to sound this influence was proved to be conformable to the demands of theory by numerous experiments of Ballot, Mach and others.

On the contrary with reference to light it has not been possible hitherto to establish by observation a trustworthy value (sicher nachweisbare Grössen) of this influence, because even the cosmical movements, which are the greatest at our disposal for this object, are very small in comparison with the rapidity of the propagation of light.

The great improvement however, which optical instruments for the observation of spectra have experienced since the dis-

* From the Proceedings of the Royal Society of Sciences of Saxony at Leipzig. Session of Feb. 6, 1869. Translated by A. N. Skinner, assistant at the Dearborn Observatory, Chicago, Illinois.

† Doppler, "On the colored light of double stars and of some other stars of the heavens." Transactions of the Bohemian Society of Sciences, vol. ii, (1841-42) p. 465-482.

covery of spectrum analysis, presents the prospect of demonstrating this influence by the spectra of the stars. According to theory this influence must show itself in a small displacement of the lines of the spectrum. For example, for a mean velocity of the earth of four German miles per second, this displacement would amount to the tenth part of the distance separating the two sodium lines. This value which is obtained in a very simple way from the velocity of light and the undulation-time of the rays corresponding to the sodium lines, has only quite lately been derived again by J. C. Maxwell, in agreement with earlier computations by F. Eisenlohr* and others.

The amount to be observed of the displacement appeared, however, to Maxwell to be so small, that he closed his considerations concerning this (having reference to the spectroscope hitherto constructed and the method of determining the position of the lines), with the remark: "It cannot be determined by spectroscopic observations with our present instruments, and need not be considered in the discussion of our observations."†

Huggins nevertheless in his most recent memoir,‡ of which the above mentioned investigations of Maxwell are an integral part, attempted the solution of the problem in question by the use of a spectroscope with no less than five prisms, of which two are Amici's, with two flint and three crown-glass prisms.

The diminution of the light caused by so great a number of prisms permits, however, the observation of only the brightest stars. Huggins indeed even confined himself to the communication of his results from observations on Sirius, and he believed here that he found a small displacement of the line F in comparison with the bright hydrogen line produced by a Geissler's tube. The direction and amount of the displacement would indicate an increase in the distance between the earth and Sirius, and this with a velocity of 41·1 English miles per second.

If we eliminate the component of the earth's movement, which at the time of observation amounted to 12 English miles, the resulting velocity with which the sun and Sirius are moving from one another would be 29·4 English miles, or about 6·5 German miles.

Huggins himself regards this result as one affected by great probable error, an error caused partly by the great weakening of the light, already mentioned, from numerous prisms, and partly by the difficulty of comparing the coincidences of the bright lines from terrestrial sources of light with the analogous dark lines of stellar spectra. The latter have sometimes a dif-

* Heidelberg Transactions of the Phys. Med. Soc., vol. iii, p. 190.

† Phil. Trans., 1868, p. 532.

‡ Ibid., p. 535.

ferent appearance; for example, they are blurred on the edge and of different breadth, as is precisely the case with the line F in the spectrum of Sirius.

The most essential of these difficulties, which have hitherto opposed a definite solution of the problem in question, I believe that I have successfully overcome, by a new construction of the spectroscope, the first example of which I have the honor to exhibit here to the Royal Society.

The arrangement is in essentials the following. The line of light produced by a slit, or a cylindrical lens, lies in the focus of a lens which as in all spectroscopes renders parallel the rays to be dispersed. Then the rays pass through two Amici's direct-vision prism-systems of excellent quality, which I obtained from the optical establishment of Merz in Munich.

These are fastened to one another in such a manner that though each passes one half of the pencil of rays proceeding from the collimator object-glass, and also so that the refracting angles lie on opposite sides. In this way the collected pencil of rays will be dispersed in the two spectra in an opposite direction. The object-glass of the observing telescope, which unites the rays again to an image, is perpendicular to the refracting angles of the prisms placed horizontally, and as in the heliometer, is divided; each of the two halves can be moved micrometrically both parallel to the line of section and perpendicular to it. By means of this we can bring the lines of one spectrum into coincidence with those of the other, and also place the spectra in immediate juxtaposition instead of superposing them, so that one spectrum moves by the other like a vernier, or we can superpose them only partially. By means of this construction not only is the delicate principle of double-images rendered available for the determination of any change whatever in the position of the lines of the spectrum, but *any such change is also doubled*, since its influence appears in the two spectra in an opposite sense.

The principal of the reversion of spectra which lies at the foundation of the instrument described, on account of which I venture to propose for it the name "REVERSION SPECTROSCOPE," can be introduced without using Amici's systems of prisms. It is only needed to reverse one part of the pencil of rays proceeding from a common prism by reflection on a mirror or prism, and then to observe the united pencil of rays exactly as above with a telescope furnished with a divided object-glass. Furthermore, this principle renders the simultaneous introduction of artificial sources of light for the investigation of small changes of refrangibility wholly unnecessary, and permits the perception and measurement of these changes, by means of the changes in position of objects completely similar in kind.

The series of measurements which was carried out both on the dark D line of the solar spectrum, and also on the bright sodium lines of a candle flame impregnated with common salt, (and these I venture to add here to show the working power of the instrument), authorizes the hope, that with the aid of this spectroscope we shall succeed not only in perceiving the influence of the earth's movement, but also in determining it quantitatively with such accuracy as appears desirable for an approximate (vorläufig) control of theoretical conclusions.

The numbers cited denote the parts of the micrometer-screw, and refer to the distance between the two sodium lines:

Sodium flame.	Sun.
49.5	49.5
50.5	51.5
53.0	48.1
49.5	48.9
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50.6 \pm 0.6	49.6 \pm 0.5

In the following series of observations the reversion spectroscope was furnished, not only with another micrometer-screw with a somewhat coarser thread, but also with two other systems of prisms whose dispersion in the region of the sodium line is 1.77 times greater than that of the systems used for the above measurements. Likewise the old achromatic object-glasses of the collimator and the observing telescope were replaced by unachromatic ones, by which not only nothing was lost in sharpness of the images, but, as was designed, an advantage was gained in clearness and distinctness by increasing the intensity of light.

SUN.	
Screw divisions.	Deviation from mean.
67.1	—0.8
69.4	+1.5
68.4	+0.5
67.9	0.0
66.6	—1.3
66.1	—1.8
68.2	+0.3
68.0	+0.1
69.6	+1.7
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Mean 67.9 \pm 0.3	

According to this, the interval between the two D lines was accurately determined, with a probable error of $\frac{1}{2} \frac{1}{26}$ of its value. But in accordance with facts previously presented, a change of the distance separating the source of light and the spectroscope, with a velocity of four German miles per second, will effect a corresponding displacement of the lines of the two spectra, to the amount of $\frac{1}{3}$ of the interval of the D lines, a quantity which

is also about forty times greater than the probable error found above for the mean of nine readings.

If, therefore, in the observation of stellar spectra, a sufficient amount of light can be used, it can be definitely determined in the way stated, whether the expected displacement of the lines of the spectrum occurs or not. In reference to the intensity of light required, I venture to remark, that, for these observations, an unachromatic lens* of one Paris foot in aperture and six feet focal length is at our disposal; its cone of rays one inch from the focus is acted upon by a suitable concave meniscus of flint-glass, and, freed thus as much as possible from spherical and chromatic aberration, is directed to the slit of the spectroscope. I feel that I should here especially point out the fact, that, in the use of a slit, the achromatism of the optical image, for the observation of its spectrum, (especially of individual parts of it), is unessential, and consequently the construction indicated here must claim the important preference of great cheapness in comparison with those with achromatics of strong light. Evidently this advantage must be given up in those cases, where, as in double stars, the desideratum is the sharpest possible separation of the objects under investigation.

I may be permitted perhaps to make some remarks upon problems and methods which refer to spectrum observations on the sun and with which I am at present employed.

The sun possesses a velocity of rotation, by virtue of which a point on its equator moves with a velocity of about 0.25 German mile. If, therefore, with the aid of a heliometer, or in any other way, we produce a double image of the sun, and by a suitable arrangement bring into contact two points of the equatorial limb, then at the point of contact, parts of the sun's surface border upon one another, one of which approaches us with a velocity of the given amount, and the other recedes from us with the same velocity. From this arises a difference of velocity of the parts in contact, in the direction of the line of sight, of about half a German mile. According to previous statements such an amount of movement would cause a change of position of the sodium lines corresponding to the 80th part of the interval between them. Therefore if by combination of a sufficient number of prisms, we succeed in perceiving such a quantity, so as to measure it, we need only to bring the middle of the slit into the line joining the two centers of the images of the sun which are tangent to each other in order to see the two spectra of the sun's limbs which are thus in contact, close together in the field of view, and then, under the most favorable relations, to observe the displacement in question. In this way then the position of the solar equator, and, in case of the

* Made in the optical establishment of H. Schroeder in Hamburg.

practicability of measurements, the velocity of rotation in various heliographic latitudes would be determined, which would be of the greatest interest with reference to the opinions pronounced most recently on this point.

But even without regard to a quantitative determination of the phenomenon in question, by means of a proof of it only qualitative, even a simple means would be found of separating *all the lines which arise from absorption in the earth's atmosphere, from those which owe their origin to the solar atmosphere*, since the displacement in question could evidently extend only to the latter.

Another subject for the investigation of spectrum analysis is the protuberances. As is well known, Lockyer and Janssen were the first who succeeded, independently of a total eclipse of the sun, in observing the spectra of these forms, which consist of three bright lines.

At the present time it is the object of most earnest endeavor to discover any methods which permit not only the observation of these lines but also simultaneously of the entire shape of the protuberance.

The length of the bright lines corresponds to the magnitude of the dimension of the protuberance concerned, which occurs in the direction of the slit. Consequently if we bring the slit successively into different positions so that it cuts the protuberance in as many directions, then we are able to construct the form of the image observed, as Lockyer has already done. Thereupon Janssen has proposed the construction of a rotating spectroscope, in order thus with a sufficient rapidity of rotation to survey rapidly the form of the whole protuberance during the continuance of the impression of light.

Leaving out of consideration the mechanical difficulties of such a rotating spectroscope in which one of the bright protuberance lines must lie accurately in the axis of rotation, the design in view can be accomplished in a simpler and more complete manner by an oscillation of the slit perpendicular to its direction. In this way the protuberance could be observed in three differently colored images corresponding to the three different lines of its spectrum.

In this method, with a movable slit, the changes of brightness, through which the protuberance passes from its base, will however be considerably weakened, in proportion to the length of the path passed over by the slit; in the rotating spectroscope especially, the brightness of the protuberance itself would be weakened from the center of rotation out to the edge, and consequently the observation of the natural relations of the brightness of the image would be frustrated.

For this reason I have in view the introduction of another

very simple method for the attainment of the object in question, of the practicability of which I am already convinced by experiments on terrestrial sources of light, to be described more in detail below. The principles on which this method depends are the following:

1. The apparent brightness (*glanz, claritas visa*)* of a strip of a protuberance is independent of the aperture of the slit under the hypothesis that it continues to have a perceptible breadth on the retina.

2. The brightness of the superposed spectrum increases proportionally to the width of the slit.

3. With an oscillating or rotating slit, the brightness of the superposed spectrum remains unchanged, while that of the image of the protuberance arising from the permanence of the impressions of light, diminishes on the other hand in accordance with a law depending on the number and duration of the excitations of the point of the retina concerned, which occur in a unit of time, and also upon the refrangibility of the strip of the protuberance observed.

If, for simplicity's sake, we suppose that the entire surface, over which the slit moves in its rotation or oscillation, is filled up by the protuberance, and if we suppose also that the intensity of the image arising, is inversely proportional to that surface, (corresponding to a uniform extension, over the surface, of the light passing through the slit), then under the assumption of the above three propositions, the relation of intensity between back-ground and protuberance, would remain the same; and we may

First, reduce the brightness of the image of the protuberance by an *oscillation* of the slit, and by this leave unchanged the brightness of the superposed spectrum (by 2); or we may

Secondly, open the slit *unmoved* so far that its aperture extends at once over the space, which in the first case the oscillation extended over. In this (by 1) the apparent brightness of the protuberance remains unchanged, but that of the back-ground is increased in the same ratio that it was previously weakened. Consequently under the suppositions made, the designed object would be accomplished much more simply in the second way, if, because of its blinding, care is continually exercised that the intense light of the real body of the sun should not penetrate the slit.

The slit need be opened only just so far that the protuberance or a part of it may appear in the opening. A suitable weakening of the entire field of view must be provided for, by means of polarizing or absorbing media, which are to be placed before the eye-piece, in order that the relative intensity between the

* Lambert, Photometria, etc. §§ 36 and 37.

protuberance and the superposed spectrum may be permitted to stand out as strongly as possible to the perception.

Led by these conclusions, I have sought, with the aid of terrestrial sources of light, to realize the conditions under which the protuberances are visible, in order, in this way, to test both methods and to convince myself of their practicability. For the better comprehension of the described experiments, let the following remarks first be premised.

The reason why the protuberances are invisible under ordinary circumstances, by screening off the intense image of the sun to the edge, lies in the strongly illuminated part of our atmosphere covering the image of the protuberance. In a total eclipse of the sun this superposed light is weakened to such an extent, that then the intensely illuminated protuberances raise themselves from the illuminated parts of the corona.

We can make an approximate estimate of the amount of the reduction of the diffused light of our atmosphere required for this, if we assume the mean illumination of the atmosphere in a total eclipse equal to that of a mean full moon. According to my photometric measurements* this illumination is 618000 times weaker than that produced by the sun; consequently then the selective absorption of colored media must stand in a similar relation in reference to the homogeneous light of protuberances, if we wish to make the protuberances visible in this way without dispersion as is generally sought at the present time.

On the contrary the possibility of accomplishing this end, with the aid of the prism by the dispersion of the superposed atmospheric light, depends essentially upon the circumstance, that this light is composed of rays of all degrees of refrangibility, while that of the protuberances, however, is composed of only three homogeneous assemblages of rays.

The superposition of an unhomogeneous mass of light upon a body shining with homogeneous light and limited by sharp boundaries, I have accomplished artificially, in the following way. The wick of an alcohol flame was impregnated with chlorid of sodium and chlorid of lithium. At a distance of 18 feet before this flame, a piece of plate glass was so set, at an angle of 45° to the direction of the observation, that the reflected image of a petroleum flame at one side covered the faintly shining alcohol flame, and, by reason of its much greater intensity, rendered it completely invisible. About one foot before the reflecting plate of glass, was situated a small lens of six inches focus, which directed a small image of the alcohol flame to the slit of the spectroscope. The latter was fastened to the end of a spring ten inches long, by means of which it could be put in oscillation of sufficient magnitude for about five minutes by

* *Photometrische Untersuchungen*, etc., p. 105, fol., Leipsic, 1865.

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first removing it from its place of equilibrium and then releasing it. Next then, the aperture of the slit was so far decreased, that, with the slit at rest, the double line D and, proportionally faint, the lithium line also appeared sharply defined in the field.

As soon as the slit was put in oscillation, these lines transformed themselves into sharp images of the alcohol flame, of which the two sodium images covered about half. The apparent brightness of these three images was much less than that of the bright lines, and in consequence of this also their relief from the diffusely illuminated spectrum ground was in the same ratio less distinct than that of the lines with the slit in a state of rest.

When now I made use of the second of the above proposed methods, and opened the unmoved slit so far that the little image of the alcohol flame was only just contained by the rectangular aperture of the slit, I was surprised by a far greater delicacy and distinctness, with which the image of the flame relieved itself from the diffusely illuminated spectrum ground. Consequently the above reduction of the apparent brilliancy of the protuberance with an oscillating slit, assumed in the theoretical discussion to be in accordance with a simple law, appeared quite strongly to incline our favor to the method last employed.

I remark here that for this experiment only one of the above mentioned new prisms was employed. But it is evident that with an additional dispersion, the diminution of the superposed unhomogeneous light can be increased at pleasure.

As may be seen, no difficulty in principle stands in the way of the application of this method to the protuberances of the sun.* Practical success, however, is dependent essentially on this, whether a sufficiently strong dispersion of light can be obtained for the actual relation of intensity between the homogeneous light of the protuberances and of the superposed light of the atmosphere. If, however, we are authorized to conclude upon a very considerable relative brilliancy of the protuberances, from the intensity and distinctness with which their lines, especially the middle one, appear,—of which I am convinced by an actual inspection on the 24th of December of the past year at the observatory at Berlin,—then the means at my command at present consisting of four excellent systems of prisms must indeed be sufficient to solve satisfactorily in the way here proposed the problem of the visibility of the protuberances.

Supplement.

According to a communication by letter, lately received from Dr. Schallen at Cologne, Mr. Lockyer also has succeeded in

* On account of an incomplete arrangement of the instrument demanded I have till now been obliged to refrain from an actual trial of this method on the sun.

observing the solar protuberances in their whole extent, according to the method developed by me in the above communication. By this communication, Mr. Lockyer has employed a spectroscope with *seven* prisms, and has communicated his results in a report held in the Royal Institution, which ought to appear in print June 15th. Since I have neither received this report up to the present time, nor even learned any details concerning Mr. Lockyer's results, it may be permitted me here to communicate the following in regard to the procedure employed by me.

The spectroscope, which has been made according to my designs in the optical establishment of Mr. Fauber in Leipsic, possesses one excellent direct vision prism by Merz. The spectroscope was fastened in a suitable way to the six feet refractor of this observatory. The height of the slit amounted to $6' 20''$ of arc, and the aperture varied with the height and magnitude of the protuberance observed. And here let it be remarked that it is most advantageous in observing to bring the length of the slit tangent to the sun's limb. By this plan on the one hand a greater segment of the sun's limb is surveyed at one view, and on the other the advantage is gained of determining with great accuracy the position angle of the protuberance, since the entrance of the sun's disc makes itself immediately noticeable by a flashing out of a narrow band-formed spectrum in the middle of the field of view. This point of the first flashing out can be easily brought to the place of the protuberance in question by revolving the spectroscope about its longitudinal axis, and in this case, as is readily perceived, the slit is tangent to the point of the sun's limb occupied by the protuberance. The actual place of the spectroscope can be read off on a divided circle, and this gives the position angle of the protuberance.

In order to bring individual points of the sun's limb conveniently before the slit of the spectroscope, two different methods can be employed. By one method the object-glass of the refractor is so fastened in a ring that its optical axis is inclined about $15'$ to the longitudinal axis of the telescope. If this ring is revolved by the help of a screw on the telescope to be worked by the observer, the optical axis of the object-glass describes a cone of about $30'$ opening, so that successively different parts of the limb come in focus before the middle of the slit. Of course the position of the slit must be varied in a corresponding way by a revolution of the spectroscope.

By the other method, which affords the advantage of an unchanged position of the slit, the rays before their union into an image are sent through a reversion-prism, so called. If this is rotated about the axis of the instrument, the image of the sun also revolves about its center and permits successively different points of the limb to fall on the slit. The angle of position is determined by the position of the reversion-prism.

The size of the sun's image in the refractor, or, in other words, the focal length of the object-glass employed, plays an important part in the whole method. It follows immediately from the theory of the method developed above, that *with the same spectroscope* the contrast between protuberance and back-ground is dependent only upon the width of the slit. Since, then, with a *constant* width of slit, the smaller the sun's image, so much a greater part of the protuberance is surveyed at once, it follows that we must not seek to accomplish the amplification of the protuberance by the sun's image, that is, with a long focus of the object-glass of the refractor, but as much as possible by the lens apparatus of the spectroscope. This can be easily accomplished by using a collimator with a relatively short focus to that of the object-glass of the refractor. Suppose, for example, we have a refractor of ten feet focus with a spectroscope attached, in which the focal length of both object-glasses are equally large. If now with this it is required to open the slit to the breadth of one millimeter in order to take in at one view a protuberance of a certain size, with an image of the sun $\frac{1}{10}$ smaller, this aperture could be reduced to $\frac{1}{10}$ of a millimeter, through which not only can the protuberance be seen in its whole extent, but also with a ten times greater contrast with the spectrum back-ground. In order now to obtain again the amplification of the protuberance *in the field of view*, which was lost by the diminution of the sun's image, the focus of the collimator need only be made ten times shorter than that of the spectroscope. To continue with the example proposed, a ten times better effect would be obtained, *giving the same optical amplification* of the protuberance *with the same prism systems*, if there is chosen in place of the ten feet refractor a telescope of only one foot focus, and for the focal distance of the collimator about two inches, and that of the observing telescope about twenty inches. The quality of the images in this is influenced very little, as far as affected by the lens system, since the defect of chromatic aberration does not enter at all on account of the homogeneity of the light of the protuberances; consequently, properly selected unachromatic lenses can be used for such combinations without any hesitation, as I have convinced myself by numerous trials. The extraordinary compactness which such instruments for the observation of the solar protuberances possess, permits a very delicate clock movement, and presents the prospect of realizing in this simple way the idea expressed already in my former communication, namely, an artificial total eclipse of the sun, of an arbitrary length, for the observation in the future of all the protuberances present on the sun's limb at the same time.

Leipzig, August 26, 1869.