

the temperature be raised equally and the volume retained at its original value, no deposition takes place. Those experiments have been done with such solvents as alcohol (ethyl and methyl), ether, carbon disulphide and tetrachloride, paraffins, and olefines, and such solids as sulphur, chlorides, bromides, and iodides of the metals, and organic substances such as chlorophyll and the aniline dyes. Some solutions show curious reactions at the critical point. Thus ethyl alcohol, or ether, deposits ferric chloride from solution just below the critical point, but re-dissolves it in the gas, when it has been raised 8° or 10° above that temperature.

It appeared to us to be of some importance to examine the spectroscopic appearances of solutions of solids when their liquid menstrua were passing to the gaseous state, but as all the substances we have yet been able to obtain in the two states give banded spectra with nebulous edges, we are only able to state that the substance does not show any appreciable change at the critical point of its solvent. Such was the case with anhydrous chloride of cobalt in absolute alcohol. It was suggested to us by Prof. Stokes that the substance obtained by the decomposition of the green colouring matter of leaves by acids, and which yields a very fine absorption spectrum, might be useful for our purpose. We have prepared the substance according to the careful directions so kindly furnished us by Prof. Stokes, and find that it shows the phenomenon in a marked manner, whether dissolved in alcohol or ether. The compound is easily decomposed by heat under ordinary circumstances, and yet can be dissolved in gaseous menstrua, and raised to a temperature of 350° without suffering any decomposition, showing the same absorption spectrum at that elevated temperature as at 15° .

We considered that it would be most interesting to examine by this method a body such as sodium, which, besides being an element, yields in the gaseous state sharp absorption lines. An opportunity seemed to be afforded by the blue solution of sodium in liquefied ammonia, described by Gore,¹ but we found that, on raising the ammonia above its critical point, the sodium combined with some constituent of the gas, forming a white solid, and yielding a permanent gas, probably hydrogen.

There seems, in some cases, to be a slight shifting of the absorption bands towards the red, as the temperature rises, but we have as yet been able to make no accurate measurements.

When the solid is precipitated by suddenly reducing the pressure, it is crystalline, and may be brought down as a "snow" in the gas, or on the glass as a "frost," but it is always easily redissolved by the gas on increasing the pressure. These phenomena are seen to the best advantage by a solution of potassic iodide in absolute alcohol.

We have, then, the phenomenon of a solid with no measurable gaseous pressure, dissolving in a gas, and not being affected by the passage of its menstruum through the critical point to the liquid state, showing it to be a true case of gaseous solution of a solid.

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ON PHOTOGRAPHING THE SPECTRA OF THE STARS AND PLANETS²

FOR many years it has seemed probable that great interest would be attached to photographs of the spectra of the heavenly bodies, because they offer to us conditions of temperature and pressure that cannot be attained by any means known at present on the earth. The especial point of interest is connected with considera-

tions regarding the probable non-elementary nature of the so-called elementary bodies. There has long been a suspicion in the minds of scientific men that one or more truly elementary bodies would be found from which those substances which have not as yet been decomposed are formed. The recent publications of Lockyer have attracted particular attention to this topic.

The most promising laboratory processes for accomplishing the dissociation of our present elements depend upon the action of heat, especially when accompanied by electrical influences, and upon relief of pressure. But the temperature we can employ is far below that found in the stars, which is comparable only with the heat of our sun, and when in addition the application of heat is restricted by the narrow range of circumstances under which we can also reduce the pressure, complete success seems to be impracticable in the laboratory.

But in the stars, nebulae, and comets, there is a multitude of experiments all ready performed for us with a variety of conditions of just the kind we need. It remains for us to observe and interpret these results, and this is the direction I have sought to pursue.

There is but one mode of investigation that can add materially to the knowledge astronomy has given us of the heavenly bodies that is the spectroscopic. This in its turn is capable of a subdivision into two methods, one by the eye, the other by photography. Each of these has its special advantages and each its defects. The eye sees most easily the middle regions of the spectrum, and can appreciate exceedingly faint spectra; by the aid of micrometers it can map with precision the position of the Fraunhofer lines, and by estimation it can with tolerable accuracy approximate to the relative strength, breadth, and character of these lines. The character of the spectrum lines is, however, of great value for the purposes we are now speaking of, and the greatest precision is needed. Photography, on the other hand, as applied to faint spectra, deals mainly with the more refrangible region, and cannot at present be employed in stellar work below the line F. Fortunately there is no break in the spectrum between the place where the eye leaves off and photography begins, and hence the two methods lend one another mutual assistance. The photograph, when suitably accommodated with a standard reference spectrum from some known source, gives valuable indications as to the positions and all the peculiarities of the lines.

But the application of photography to the taking of stellar spectra is surrounded by obstacles. These are partly due to the small quantity of light to be dealt with, and partly to the fact that it is necessary to overcome the motion of the earth and other causes, such as atmospheric refraction, which seem to make a star change its place continually. The exposures of the sensitive plate require to be sometimes for two hours, even with a large telescope; and if during that time the image of the star at the focus of the telescope has changed place $\frac{1}{300}$ of an inch, the light no longer falls on the slit of the spectro-scope. The changes of the earth's atmosphere in regard to photographic transparency, as well as by fog, also offer impediments and promote the chances of failure. There is often a yellow condition of the air, which may increase the length of exposure required forty times or more.

It will from what has been said above, be readily perceived that a research such as this consumes a great deal of time; in fact, these experiments and the preparations for them have extended over more than twelve years. A large telescope is required, and for many reasons the reflector at first seems most suitable. Recently, however, I have found that the refractor has also some special advantages.

In 1866 I had already constructed a silvered glass reflector of $15\frac{1}{2}$ inches aperture, which was commenced in 1858, and had taken with it many hundreds of photographs of the moon. But as the mounting had been

¹ Proc. Roy. Soc., vol. xxi, p. 145.

² Read before the National Academy of Sciences, October 28, by Henry Draper, M.D.

contrived for lunar photography and to avoid the moon's motion in declination, the instrument was not suitable for the spectroscopic work contemplated. A reflector of 28 inches aperture was therefore commenced in 1866, and in 1871 it was ready for use.

On May 29, 1872, my first photograph of the spectrum of a star was taken, the spectrum of Vega being photographed by the aid of a quartz prism. At this time I did not happen to know that Dr. Huggins, who is so distinguished for his thorough and accurate researches on the visible portion of the spectra of the heavenly bodies, had already made some attempts in this direction, as is shown by the following paragraph from the *Transactions* of the Royal Society for 1864:—"On the 27th of February, 1863, and on the 3rd of March of the same year, when the spectrum of Sirius 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 farther, but we have not abandoned our intention of pursuing them."

During August, 1872, I took several photographs of the spectrum of Vega, and these showed four strong lines at the more refrangible end of the spectrum, the least refrangible being near G. On pursuing the subject and seeking to ascertain what substances gave rise to these lines, it became obvious that a photographic study of this part of the spectrum for the metals and non-metals was necessary to interpret the results. This, of course, opened out a large field for experiment, requiring many years for its study, and hence, as several physicists were engaging in the study of the spectra of the metals, I concluded to discontinue the experiments commenced in 1870 on the spectra of the metals and to confine the investigation mainly to the non-metals. The initial step was, however, to obtain a fine photograph of the normal solar spectrum, so that the wave-lengths of the lines up to O [wave-length 3440] might be determined with precision.

In the spring of 1873 I published a paper on the diffraction spectrum of the sun, illustrated by a photograph embracing the region from wave-length 4350, near G, to 3440, near O, and in the fall of the same year took photographs of the spectra of several non-metals, notably nitrogen, carbon, and oxygen. The experiments were interrupted, in the spring of 1874, by going to Washington to superintend the photographic preparations for the United States observations on the transit of Venus.

Since that time my experiments have been divided into two parts, an astronomical portion occupying principally the summer season, and a laboratory portion during the rest of the year. The former consisted of photographs and observations on the spectra of the stars, planets, and sun; the latter of photographic work on the spectra of the elements, and particularly the non-metals, and has led to the discovery of oxygen in the sun.

In 1876 Dr. Huggins published a note in the *Proceedings* of the Royal Society, accompanied by a wood-cut of the spectrum of Vega, with a comparison solar spectrum. Seven lines were observed in the spectrum of Vega. In the summer and autumn of 1876 I made several photographs of the spectra of Vega, α Aquilæ, and Venus, and sent a note concerning them to the *American Journal*.

Since that time Dr. Huggins has pursued the subject actively in spite of the London atmosphere, and has attained very fine results, which I had the pleasure of seeing at his observatory last spring. These he is preparing to publish shortly. In my observatory photographs have been taken of the spectrum of Vega, Arcturus, Capella,

α Aquilæ, Jupiter, Mars, Venus, the moon, &c. Recently the plan has been to have a comparison solar spectrum on every plate, derived either from the diffused light of our atmosphere or from the moon or from Jupiter. In this way no difficulty in determining the wave-lengths of the lines is encountered, and the changes produced by our atmosphere are eliminated. The telescope and spectro-scope are now in good working order, but to secure the requisite degree of precision of movement it has been necessary to make seven different driving-clocks before a satisfactory one was attained.

It has been remarked that on account of the faintness of the light of stellar spectra, prolonged exposures of the sensitive plate are required. In former times, when the dry processes of photography were much less sensitive than the best wet plates, the exposure was limited by the length of time the plate could be left in the camera without being stained by drying. But now, since the gelatino-bromide process has been introduced, this obstacle has been removed and a sensitive plate is sometimes exposed two hours to the spectrum of a star and then almost an hour to Jupiter for the comparison spectrum. The best, and most sensitive, gelatine plates I have used are those made by Wratten and Wainwright, of London; Dr. Huggins was good enough to call my attention to them.

It is not worth while to describe the various forms of spectroscope that have been employed in the last ten years; quartz, Iceland spar, hollow prisms and flint glass have been the materials, and they have been sometimes direct vision and sometimes on the usual angular plan. Gratings on glass and speculum metal given to me by Mr. Rutherford have been tried. The length of spectro-scope has been sometimes 28 feet and sometimes not as many inches.

The especial spectroscope for stellar work that is now on the telescope is intended to satisfy the following conditions: (1) to get the greatest practicable dispersion with the least width of spectrum that will permit the lines to be seen; (2) to use the entire beam of light collected by the 28-inch reflector or 12-inch achromatic without loss by diaphragms; (3) to permit the slit to be easily seen so that the star may be adjusted on it; (4) to avoid flexure or other causes that might change the position of the spectrum on the sensitive plate in pointing the telescope first on one and then on another object; (5) to admit of observing the spectrum on the sensitive plate at any time during an exposure without risk of shifting or disarrangement. The dispersion is produced by two heavy flint prisms which are devoid of yellow colour; the telescopes are about 6 inches in focal length, and the slit has a movable plate in front of it, enabling the operator to uncover either the upper or the lower portion at will.

During the past summer this spectroscope has been used with the Clark refractor of 12 inches aperture, partly because the 28-inch reflector has been kept unsilvered since it was used in taking photographs of the transit of Mercury, on account of its employment in certain experiments on the sun. Moreover, there is an advantage possessed by the refractor for this work which does not appear at first sight. Naturally one supposes that a refractor which brings all the rays from the star, no matter what their refrangibility, to a focus in one plane, would be best, because when the slit is put in that plane it is equally illuminated by rays of all refrangibilities, and the spectrum will be parallel-sided in its whole length. On the other hand a refractor is not achromatic, for the violet end of the spectrum comes to a focus either inside or outside of the plane of the rays in the middle of the spectrum, and in observing the spectrum it is not parallel-sided. This peculiarity was used by Mr. Rutherford to enable him to correct a telescope lens for the ultra-violet rays. It is easy, therefore, with a refractor, so to adjust the position of the slit that you may have a spectrum

tolerably wide at F and G, and which gradually diminishes in width towards H, and finally becomes linear at M. Now as the effect of atmospheric absorption on the spectrum increases as you pass from G toward H and above H, by diminishing the width of the spectrum you can in some measure neutralise the effect, and at one exposure obtain a photograph of nearly uniform intensity from end to end, though it is of variable width. If it were not for this it would be necessary to have the spectrum over-exposed at G in order to be visible above H, or else to resort to an elaborate diaphragming which is difficult.

It is my intention next season to return to the use of the 28-inch reflector, because it collects nearly five times as much light as the 12-inch does, after making allowance for the secondary mirror. Of course in a large reflector the difficulties of flexure and instability of the optical axis are much increased, and keeping a star on the slit will be troublesome, especially as the magnifying power on the image is about 50.

As to the results obtained, it has already been mentioned that the spectra of several stars and planets have been photographed. The subject of planetary spectra will be reserved for a future communication. A preliminary examination at once shows that these stellar spectra are divisible into two groups: (1) those closely resembling the solar spectrum, and (2) those in which there are relatively but few lines, and those of great breadth and intensity. The photographs of the spectra of Arcturus and Capella are so similar to the solar spectrum, that I have not up to the present detected any material differences. But, on the other hand, the spectra of Vega and α Aquilæ are totally different, and it is not easy without prolonged study and the assistance of laboratory experiments to interpret the results, and even then it will be necessary to speak with diffidence. I have not as yet obtained any stellar spectrum photographs belonging to the third and fourth groups of stellar spectra as described by Secchi. These, if obtainable, will aid materially in discussing the whole subject, but unless a star passes near the zenith it is hard to make a fair study of its spectrum by photography, because atmospheric absorption in the ultra-violet region increases rapidly as the altitude decreases. In the case of the sun I have found that at sunset the exposure necessary to photograph the spectrum above H, is often 200 times as long as at mid-day.

In the case of the spectrum of Vega, when examined by the eye, the lines C, F, near G and h , are readily visible, but lines such as D and b are relatively faint. It is clear, then, that hydrogen exists to a large extent in the atmosphere of that star. But on examining the photograph of its spectrum it is evident that other lines just as conspicuous as the hydrogen lines, are present. One of these corresponds in position and character to H₁, and seems to coincide with a calcium line. It appears to me, however, that the evidence of this coincidence is not complete.

In attempting to reason from these photographs as the matter now stands, it is necessary to try at every step farther experiments in order to find out whether the facts agree with the hypothesis, and it is this very condition of affairs that gives hopes of results valuable in their bearing on terrestrial chemistry and physics. In the photographs of the spectrum of Vega there are eleven lines, only two of which are certainly accounted for, two more may be calcium, the remaining seven, though bearing a most suspicious resemblance to the hydrogen lines in their general characters, are as yet not identified. It would be worth while to subject hydrogen to a more intense incandescence than any yet attained, to see whether in photographs of its spectrum under those circumstances any trace of these lines, which extend to wave-length 3700, could be found.

It is to be hoped that before long we may be able to

investigate photographically the spectra of the gaseous nebulae, for in them the most elementary condition of matter and the simplest spectra are doubtless found.

THE FUNCTION OF CHLOROPHYLL

THE Report of the Berlin Academy for July last contains a remarkable paper by Prof. Pringsheim on this subject. In pursuing his researches upon chlorophyll, he had found that positive results could only be obtained by employing *intense* light, and in this paper he gives some account of the conclusions at which he has been enabled to arrive by the use of this method.

By means of a heliostat and a strong lens, the object to be observed under the microscope is brightly and constantly illuminated; the effects of this illumination, which are striking, are produced in a few (3-6) minutes. Assuming that the object contains chlorophyll-corpuscles, the first visible effect is the rapid disappearance of the green colour, so that the object appears as if it had been lying for some days in alcohol, the corpuscles retaining however their form and consistence. Changes now gradually become apparent in the protoplasmic contents; the circulation of the protoplasm, where it exists, is arrested; the bridges of protoplasm rupture, and the nucleus is displaced; the ectoplasm contracts, becomes permeable to colouring-matters, and the turgidity of the cell disappears; the cell presents, in fact, all the symptoms of death.

It seems natural to suggest that these effects may be due, to some extent at least, to the action of the high temperature to which the cell is exposed under these conditions. Prof. Pringsheim, anticipating this criticism, is careful to point out that they are produced by all the different parts of the visible spectrum. They are quite evident when the light has previously passed through a solution of iodine in carbon disulphide, but they are more distinct when the light has passed through an ammoniacal solution of cupric oxide; the light to which the object is exposed consisting, in the former case, of red rays, in the latter, of blue and violet. Moreover, if the solution of iodine be so concentrated that only the rays of a greater wave-length than 0.00061 m.m. can pass, these effects are not produced although about eighty per cent. of the heat is transmitted; on the other hand, if the ammoniacal solution of cupric oxide be so concentrated that the whole of the rays of low refrangibility to a wave-length of 0.00051 m.m. are absorbed, the effects are rapidly and vividly produced, although the amount of heat which passes is comparatively small. From these facts he concludes that the phenomena in question are the results not of the action of heat, but of that of light.

This important point being settled, he proceeds to determine in what manner this action of the intense light is affected by the atmosphere in which the object exists. As the result of a variety of experiments he finds that these effects are only produced when the atmosphere contains oxygen.

These are very briefly the facts which Prof. Pringsheim has ascertained by this method; we will at once pass to the consideration of the conclusions which he draws from them. He concludes, in the first place, that the decomposition (oxidation) of chlorophyll in the living plant is a process of combustion which is influenced and promoted by the action of light, and which stands in no relation to the decomposition of carbonic acid by the plant. Since the green colour of the chlorophyll-corpuscles which have become blanched is not subsequently restored, even though the cell continue to live, it appears that this oxidation of the chlorophyll is not a normal physiological occurrence, but that it is purely pathological. Prof. Pringsheim was unable to find any substance in the cells which might be regarded as the product of the oxidation of the chlorophyll, neither could he detect any increase