OPENING ADDRESS.

PAPER I.—ON RECENT SPECTROSCOPIC OBSERVATIONS OF THE SUN, AND THE TOTAL ECLIPSE OF THE 7TH AUGUST, 1869.

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(Read before the Society on the 5th and 7th of January, 1870.)

I have selected as the subject of the address, which I have the honor to deliver this year, as your President, "Recent Spectroscopic Observations of the Sun, and the Eclipse of August 7th, 1869." I have been induced to choose this subject, because in no branch of science have more novel and startling discoveries been made than those that have of late rewarded the spectroscopist;—because the eclipse of August last was a matter of deep interest over the whole continent, and will prove to have been an event of great scientific importance, when all the observations made of it are published and compared; and because one of the leading members of your own society—your learned ex-President, Com. Ashe—had charge of an expedition, whose labours will, it is believed, not prove to have been valueless.

Astronomy is no longer a purely mathematical science, treating of the distances and magnitudes of the celestial bodies; nor is the telescope the only instrument by means of which the condition of these far-distant worlds can be studied. The spectroscope now enables the astronomer to determine of what the sun and many of the fixed stars are composed; whether they possess an atmosphere, and what elements exist in it; whether they are self-luminous or only reflect borrowed light; what burns in the flaming tail of the comet, and what those mysterious clouds of light—the nebulæ—are. I will briefly describe this instrument and the phenomena it reveals, as an indispensable introduction to our subject.

Newton, in his famous treatise on optics, first explained the properties of white light, shewing that it might be decomposed by its passage through a prism, into a continuous band of seven colours, and these coloured bands recomposed into white light, by repassing through a second prism. These and other experiments led him to the conclusion that light which differs in colour differs also in refrangibility. The seven prismatic colours visible under ordinary circumstances, beginning with the least refrangible, are, red, orange, yellow, green, blue, indigo, and violet.

When the prismatic spectrum is produced by a Drummond lime light—which emits pure white rays,—there results a continuous band of colours, gradually merging one into another, unbroken by lines either bright or dark. Wollaston, however, in 1802, observed that the spectrum given by sunlight was traversed by dark lines, which retained constantly the same relative distance from each other, and always occupied the same relative positions in the seven coloured spaces; but it remained for Frauenhofer to make the first map of these lines, and to detect the same lines in the light reflected from the moon and planets, but a different series of lines in the light issuing from the fixed stars. What produced the lines he could not guess, but he rightly conjectured it must be some cause operating beyond our atmosphere, otherwise the spectra would have been similar in all cases. The lines are justly named after him, the Frauenhofer Lines.

To produce a spectrum, all that is needed is a transparent prism, which is, therefore, the essential element in the spectroscope; the other parts are accessory. As usually made, the instrument possesses one prism, or several when great dispersion is required. The light is conducted to the prism by a tube provided at the end furthest from the prism, with a kind of slide valve, worked by a delicate screw, which opens a slit of greater or less width. The tube likewise carries a lens which throws the light in parallel rays upon the prism. After passing through the prism, the coloured rays are conveyed to the eye by a telescope. Some spectroscopes are supplied with another tube containing a scale which can be thrown upon the eye side by side or superimposed upon the spectrum under examination, by means of which the relative position of its lines can be determined.

Let me now enumerate the phenomena which result from passing different coloured lights through the prism. If a piece of wire be heated in a colourless flame, when it has attained a red heat, a band of red light is yielded—that is, the space in the spectrum occupied by the least refrangible rays is filled. Gradually, as the heat is raised to whiteness, the remaining six spaces are filled ; till, when the wire has reached a white heat, a continuous complete spectrum is yielded. All white light gives a complete spectrum ; red light, or substances which burn red, gives a spectrum of red rays in the space occupied by red in the continuous spectrum; green light gives green bands; yellow, yellow bands, &c.

Most chemical elements tinge a colourless flame, when volatilized in it, with a distinctive colour. You all recollect the ghastly yellow which alcohol burnt with salt yields. The crimson colour of the Bengal lights is produced by salts of strontium. Copper is used to colour fireworks green; barium and its salts to yield green, with a shade of yellow ;—calcium, red ; potassium, purple.

Now, if sodium or its compounds (of which common salt is one) be volatilized, and the rays issuing from its incandescent vapour passed through a prism, we get, as might be expected, a yellow band ; or more properly, two narrow bands in such close approximity as to appear one, and these occupy a position in the space filled by yellow in the continuous spectrum. The spectrum of calcium consists of a group of red and yellow lines and one purple, such as when combined would produce light red ; whereas all the bright lines of the strontium spectrum, except one green, lie in the red and orange spaces. Potassium gives a spectrum of two crimson and one broad purple band ; and in the barium spectrum, yellow bands predominate. You see, therefore, that there is an intimate relation between the occular appearance of the flames of these various metals and the spectra they produce. The colour they yield to the blow-pipe flame has long been employed by chemists as a rough method of detecting their presence. The spectroscope now affords the most delicate possible instrument for attaining the same end, and has, therefore, become an important adjunct to the chemical laboratory. By its aid, four new metals have been discovered since 1860. As no better example of the accuracy of this method of analysis can be given, let me describe Bunsen's famous discovery of the metals Cæium and Rubidium. Prof. Bunsen was examining the residues left after the evaporation of a large quantity of the mineral water of Durkheim, Germany. After separating the known constituents, he ignited some of the residue in the flame of a spectroscope. The spectrum it yielded contained lines he had never observed before. He noted all the lines he was familiar with ; but there remained a large group of bright crimson, orange, and green lines, with a pair of bright blue, and another pair of purple lines, which had never before been detected. He at once decided that they belonged to metals never before examined ; and, therefore, he set about with a skill which only such masters of the science as he possess, eliminating all known substances till he left the two new elements pure and intact. So small is the proportion of either, that from 45 tons of Durkheim water, he obtained only 158 grains of Cæium and 283 grains of Rubidium. We do not know which to admire most, the consummate skill and genius of the man who could detect and separate them, or the beautiful delicacy of the instrument by means of which the discovery was made.

Burning gases act in the same way as metals when volatilized and still in a state of glowing vapor. Hydrogen, for instance, in combustion, gives a spectrum of three bright lines—a red, a bluish-green, and a purple.

But the spectroscope has a far wider application. If we throw a spectrum from glowing sodium vapor on a screen, we have two bright yellow bands on a dark back-ground. If, now, we volatilize some sodium in a sealed tube filled with hydrogen, and pass the yellow light from burning sodium through this sodium vapor, the two yellow bands produced in the first experiment are immediately extinguished. On substituting white light for the burning sodium, and passing it through the tube of sodium vapor,—we obtain a continuous spectrum traversed by two black lines, which occupy exactly the position of the two bright bands which compose the spectrum of the sodium flame. The same experiment, repeated with other substances, whether they be glowing vapors of metals or gases in a state of ignition, leads to the same results. When, for instance, white light is passed through hydrogen, the three bright lines which characterize its spectrum are reversed, and converted into three similarly situated dark lines. Certain rays of light are cut down, obliterated during the passage of the light through the hydrogen; and these are the very rays which burning hydrogen itself emits. From these facts, but one conclusion is deducible, viz., that vapors absorb rays of the same degree of refrangibility aa they emit when in a state of ignition. This law is based on so many and such consistent facts that it may be accepted as confidently as any law in chemistry or physics. Reasoning from it, we know that when a spectrum traversed by dark lines is obtained, light has passed through the vapors of the metals which would, when in a state of ignition themselves, have given a spectrum of bright lines or bands, occupying the same position as the dark lines in the spectrum under examination.

Remark now how these laws may be applied to the elucidation of some of the principal questions in solar physics.

If a properly-constructed spectroscope be slowly moved towards the sun, there will be seen at the moment before contact several bright lines, and prominent among them the three hydrogen lines; but in an instant they are extinguished and their place supplied on a bright continuous spectrum by dark lines occupying the same position, and by a host of other lines, so numerous in parts as almost to darken the spectrum. Now, what may we fairly deduce from these appearances? Surely that there is an atmosphere around the sun composed of gases and vapours in a state of ignition; and that there traverses this atmosphere from the body of the sun, or from a deeper layer of atmosphere, pure white light. This, we may without presumption suppose to emanate from the metals there in a state of incandescence whose vapours compose the solar atmosphere, unless—which as we shall see further on, is more probable—the sun be a ball of vapours and gases in which the vapours of the heavy metals occupy the centre, and those of the lighter form concentric strata towards the circumference. Around the sun the atmospheric envelope is thin and transparent: hence we get the spectroscopic phenomena of burning gases and vapours—a spectrum of bright bands; but carrying the instrument through this gaseous envelope—on touching the visible orb of the sun—we can no longer expect to have the spectrum of bright lines; for the light given off from the incandescent nucleus of the sun, if it be liquid, or the dense vapours of it be gaseous, in its passage through the gaseous envelope, loses the rays which the gases and vapours in this envelope or atmosphere absorb; and hence we have a continuous spectrum, traversed by dark lines.

Kirchhoff did not arrive at this conclusion so summarily; nor did his instruments enable him to observe all we have said may now be seen with a properly constructed spectroscope. It is only within a year and a-half that the gaseous envelope of the sun has been examined in broad day-light. The steps by which Kirchhoff arrived at his great discovery are these: He required a scale by which to map the positions of the bright lines forming the spectra of the metals, and adopted the scale which nature had prepared ready to his hand—the dark lines of the solar spectrum. In comparing the spectra of different metals with the solar spectrum, he was surprised to find that the bright lines in the spectra of most of the metals were co-incident with certain of the black lines in the solar spectrum. Great was his astonishment at finding a dark line corresponding to 80 of the lines which compose the spectrum of iron alone. Of course he concluded that iron vapour existed in the sun's atmosphere.

Further researches in the same direction, and by the same method, have resulted in the detection in the solar atmosphere of the following elements:

Sodium,
Calcium,
Barium,
Magnesium,
Iron,
Chromium,
Nickel,
Copper,
Zinc,
Strontium,
Cadmium,
Cobalt,
Hydrogen.

None of the other elements have been detected; but as many of them are among the heaviest substances known—such as gold, mercury, platinum—if the sun be a liquid or gaseous ball, they would occupy the centre of the mass, and their vapours, therefore, not exist sufficiently near the surface to reverse their spectra. When Frauenhofer first directed attention to the dark lines of the solar spectrum, he named eight of the most prominent by the first eight letters of the alphabet. Of these, there has been determined the coincidence of the

C	line	with	hydrogen and magnesium;
D	"	"	sodium;
E	"	"	iron;
F and G	"	"	hydrogen;
H	"	"	aluminium.

Till last year, the spectroscope had revealed little else respecting the physical constitution of the sun than that it possesses a gaseous envelope or atmosphere of glowing gases and metallic vapours, in which certain known and many unknown substances existed. But a solar atmosphere had been predicated on other grounds. Looking at the sun in the full blaze of day-light, one sees a fiery orb with sharply-defined circumference; but when the sun is eclipsed, by the passage of the moon between it and the observer, the surface of the sun is seen to be broken, not like that of the moon, by rugged mountain peaks and deep valleys, but by stupendous masses of burning gas, which are whirled up by storms raging over the surface of the sun, as are the pillars of sand by the sirocco of the African desert. These flames are visible beyond the disk of the moon after it has hid the luminous body of the sun. Such mountains of glowing gas have been noted during every eclipse of which we possess a scientific record; and it was observed that they spring from a ring of rosy-coloured light which enveloped the dark orb of the moon. Outside them, and extending at places for a degree beyond the sun, there was always observed an irregular halo of white light. For a long time, through the most perverse reasoning, these phenomena were supposed to be appendages of the moon; but the observations made during the eclipse of 1842, and the photographs made during that of 1860, left no doubt that these protuberances or prominences belong to a solar atmosphere, less luminous than the body of the sun.

It was after the eclipse of 1860 that the value of the spectroscope in the investigation of solar physics became evident; and therefore the next eclipse was looked forward to with eagerness as likely to enable the spectroscopist to determine beyond a doubt the nature and composition of the protuberances and the corona. Consequently, a number of expeditions left Europe to observe at different points along its central line the eclipse of August, 1868, which began in Africa, crossed the Red Sea to Aden, and then traversed the Indian Ocean, India and Malacca. A Prussian expedition, under Dr. Vogel, stationed itself at Aden, where totality occurred soon after daylight. M. Jannsen, an eminent French astronomer, made his observations at Gondoor, in India, and M. Rayet in the Peninsula of Malacca. Several English parties were organized, foremost among which were those under Major Tennant and Lieut. Herschel, both of whom took up positions in India. Dr. Vogel and Major Tennant aimed chiefly at obtaining photographs of the eclipse. During this eclipse, there were observed several large protuberances and a corona. The rosy-coloured banks of cloud whence these protuberances sprang, were lightest about the equator. One very prominent protuberance retained the same position, and underwent very little alteration in shape during the period of the eclipse. The interest of the eclipse centred in the spectroscopic observations of the protuberances. Upon the whole, the reports of the different observers accorded. They all fonnd the protuberances to give bright lines, and therefore the question of their gaseous constitution was settled. There was not quite such identity in the opinion as to the number and position of the bright lines. All the observersexcept Lieut. Herschel observed two of the hydrogen lines. The blue line which he lays down corresponds, however, so nearly to the hydrogen line, F. which the others are sure they detected, that we may consider them the same. All likewise agree in having seen a line in the yellow, near the double D line of sodium; and M. Rayet noted lines indicating the presence of iron and manganese. He distinctly observed 9 lines in one protuberance, and only eight in another. "Hence," he remarks, "all the protuberances do not emit identical light." The observations on the corona were more discordant. M. Rayet, with his powerful instrument, could not detect the faintest spectrum; whereas Major Tennant positively reports a continuous spectrum.

Capt. Branfell, of the same party, reports "the protuberances unpolarized, and the corona strongly polarized, everywhere in a plane passing through the centre of the sun." There is the usual disagreement with regard to the colour of the protuberances, Major Tennant pronouncing them white, but all others assigning to them some shade of red.

Such are the principal results of the memorable eclipse of 1868; but they were immediately thrown into the shade, and rendered well nigh superfluous, by a discovery made almost simultaneously by M. Jannsen, in India, and Mr. Norman Lockyer in England, by which the spectroscopic phenomena of the protuberances may be viewed any day without the interposition of the moon.

The coincidence in time of the same discovery by two men, at the antipodes, ranks among the curiosities of science with the simultaneous discovery of Neptune by Adams and Leverrier.

More than three years ago Mr. Lockyer conceived the idea of viewing the protuberances in full sun-light by passing a spectroscope with great dispersive power around the sun's disk. His instrument being unsuitable, one of a peculiar construction was ordered in 1867, but only finished in the autumn of 1868. His anticipations were realised by his first observation. In broad day-light, he was enabled to trace the position and shape of the protuberances upon the sun's disk, by means of the bright lines which their spectrum gave. A few days after the publication of these important results, and a few minutes after their communication to M. DeLaunay, of the French Academy, there was received by that gentleman a letter from M. Jannsen, stating that during the progress of the eclipse, he had conceived the possibility of attaining the same end by the same means as Mr. Lockyer was at that very time independently working at, and that on the following day he had experimentally confirmed his idea, and drawn the altered outline of one, the same protuberance he had observed the day before during the eclipse. Since then, these astronomers and other spectroscopists—notably Father Secchi, of Rome—have worked in the same field, and vastly enlarged our knowledge of solar physics. I can but briefly enumerate the conclusions arrived at. It is now determined, with tolerable certainty, that there is a very attenuated atmosphere of burning hydrogen enveloping the sun at every point, measuring in average height about 5000 miles ; but at certain points, and chiefly near the equator, wafted into masses of twenty times that height by solar whirlwinds, and thus forming the protuberances of the eclipse. These storms are so violent that they displace not only the light hydrogen which forms the outermost layer of atmosphere, but also project from a deeper stratum the heavier vapours of iron and other metals into the base of the hydrogen flames. This outer layer has been called the chromosphere, from its giving a spectrum of bright-colored lines. Here and there, as some of the photographs taken during the three last eclipses shew, and as spectroscopic observations verify, clouds of hydrogen are carried away burning, into space, quite detached from the visible solar atmosphere, though probably within the limits of the real atmosphere, as certain of the hydrogen lines in the spectra of the protuberance extend faintly beyond the others, and indicate the extension of the atmosphere far beyond its more perceptible bounds.

Lockyer's description of the chromosphere is quite picturesque: "In different parts the outline varies. Here it is undulating and billowy; there it is rugged to a degree; flames, as it were, darting out of the general surface, and forming a rugged, fleecy, interwoven outline, which at places is nearly even for some distances, and then, like the billowy surface, becomes excessively uneven in the neighbourhood of a prominence. Here one is reminded of the fleecy, infinitely delicate cloud films of an English hedgerow, with luxuriant elms; there, of a densely intertwined tropical forest, the intimately-interwoven branches spreading in all directions, the prominences generally expanding as they mount upwards, and changing slowly, almost imperceptibly."

Intermediate between the chromosphere, yielding its spectrum of bright lines, and the body of the sun—which gives a continuous spectrum with dark lines, may, under favourable circumstances of our atmosphere, be detected a continuous spectrum, such as a Drummond light would yield. The explanation of this is not very easy; but the following is suggested:—If we suppose the body of the sun to be liquid, the metals which compose it are in a state of fusion at a white heat, and, therefore, emit white light; if we suppose it gaseous, the mass of glowing vapor is too dense to be transparent, and, therefore, may act in the same manner as if it were liquid; but immediately outside this liquid, or gaseous nucleus, there is a layer of ignited gases and vapors, situated so near the thin outer limb of the orb as to be transparent, in which the vapors of so many metals are burning that their combined bright lines will yield a continuous spectrum, or what may appear such.

Another explanation, and a more probable one, because corroborated by experiment, has been offered. A continuous spectrum, according to Frankland and Lockyer, is given by gases when undergoing condensation. Judging from what takes place in our own atmosphere, we may suppose, as Storey has pointed out, a rapid condensation of certain of its constituents upon the surface of the sun. Such a permanent gas as hydrogen would undergo no change, and, therefore, continue burning beyond the limits of the area of condensation. This area of condensation would form a cloudy envelope, radiating back most of its heat to the sun, and serving other purposes in the solar economy. Would the reversion of the bright lines take place in this area?

There is not perfect unanimity of opinion as to the condition of the body of the sun. The old idea of a solid nucleus is now generally abandoned, and the opinion that it is liquid is yielding to the views of those who conceive that at such a high temperature as all admit prevails, it must be gaseous. There are other reasons still for believing it to be gaseous. In this latter case, there can be no well-defined atmosphere; but the term may be applied to the hydrogen or outermost stratum of gas and so much of the deeper stratum as contains the vapors necessary to give the Frauenhofer lines. The chromosphere in this view is that layer in which the reversion of the bright lines takes place, unless there be an area of condensation, as proposed above. The interior has been called the photosphere.

The solution of this doubt will probably be arrived at by more extended observations on the spectra of solar spots. These spots—as you are aware—have been the subject of much controversy, and the spectroscope has not set it at rest. It is assumed by some that there is a relation between the spots, the protuberances and the faculæ, which are generally observed in the neighbourhood of the spots. When a spot is visible on the edge of the sun's disk, a protuberance may often be detected in the neighbourhood, as, for instance, in the following observation by Mr. Lockyer :

" On the 21st April there was a spot very near the limb, which I was enabled to observe continuously for some time. At 7.30 a.m. there was a prominence visible in the field of view, in which tremendous action was evidently going on, for the C. D. and F. lines were magnificently bright in the ordinary spectrum itself; and as the spot-spectrum was also visible, it was seen that the prominence was in advance of the spot. The injection into the chromosphere surpassed everything I had seen before, for there was a magnesium cloud quite separated from the limb, and high up in the prominence itself. By 8.30 the action had quieted down, but at 9.30 another throb was observed, and the new prominence was moving away with tremendous velocity. While this was going on, the hydrogen lines suddenly became bright on the other side (the earth's side) of the spot, and widened out considerably—indeed, to such an extent that I attributed their action to a cyclone, although, as you know, this was a doubtful case. Now, what said the photographic record? The sun was photographed at 10h. 55m. a.m., and I hope you will be able to see on the screen how the sun's surface was disturbed near the spot. A subsequent photograph at 4h. 1m. p.m. on the same day, shows the limb to be actually broken in that particular place; the photosphere seems to have been actually torn away behind the spot, exactly when the spectroscope had afforded me possible evidence of a cyclone."

There are probably accumulations of hydrogen near the spots, which appear in the telescope as faculæ or willow leaves, and reveal their presence to the spectroscopist by a decided reduction in the intensity of the dark hydrogen lines, and sometimes their conversion into bright lines, even upon the surface of the sun.

The spectroscopic phenomena of the spot itself are very curious. Of course, deductions have been drawn from them; but it would be premature to put implicit reliance on them, until more extended experiments on gases at different temperatures and under varying pressure have enabled the conditions existing on the surface of the sun to be imitated and watched in the laboratory. Mr. Lockyer detects the presence of a spot by a general darkening of the spectrum and the widening of certain of the Frauenhofer lines—phenomena which he attributes to a local increase in the general and selective absorption of the chromosphere. The Frauenhofer lines put on a sudden blackness and width in the case of a spot with steep sides, but expand gradually in a shelving one. This thickening of the absorption lines, Lockyer and Frankland have proved by experiments to be due to varying pressure; and this variation in pressure they attribute to convection currents in the chromosphere: "Suppose a hydrogen flame to be suddenly projected from the sun in the direction of the earth, the waves of light will be shortened, and the hydrogen lines of the spectrum be shifted nearer the violet. If the flame travels from the earth, the waves will be lengthened, and the lines shifted nearer to the red end of the spectrum. The line F undergoes strange contortions when seen near the centre of the sun's disk. It is seen, in fact, stopping short in one of the small spots, swelling out prior to disappearance, invisible in a facula between two small spots, changed into a bright line, and widened out two or three times in the very small spots, becoming bright near a spot and expanding over it on both sides, and so on. The Frauenhofer lines may thus be looked upon as so many milestones, telling the rapidity of the uprush and downrush. Thanks to Angstrom's map of the wave-length of the different parts of the spectrum, it is known that the shifting of the F line the ten-millionth part of a millimeter nearer the violet, means a velocity of uprush to the eye of 38 miles per second. The observed alterations of wave-length is such that twenty miles a second is very common."

From this, I presume, we are to gather that Lockyer considers that the same cyclone, which whirls the chromosphere up into space, projects the heavier vapors of the photosphere into the chromosphere, and thereby leaves a cavity in the photosphere itself. This is filled by a downrush of the chromosphere, which is consequently there much thicker than in the surrounding region, and, therefore, more absorbent.

The principal objection to this view is that the changes are not so rapid in reality as the circumstances would lead us to expect they would be; for a spot remains for days visible on the surface of the sun, undergoing slight alteration in shape, whereas the prominences are comparatively evanescent.

Prof. Young, of Hanover, N.H., who is making daily observations on the spots and protuberances, does not admit so intimate a relation between them. From his observations, he considers it evident that the spots and prominences obey nearly the same laws in respect to their distribution on the solar surface; but the prominences, which are far more numerous than the spots, approach nearer to the poles, and are more frequently found on the equator. He has never yet been able to watch a spot in its passage round the limb, so as to observe its effect on the chromosphere; but his present impression is that certain depressions observed from time to time in the chromosphere, are due to spots directly under them. In only one case has he found a prominence very near a spot, and then only a small one. Whether the prominences are connected with the faculæ, he thinks, is a different question, and more likely to receive an affirmative answer.

Father Secchi's observations agree in the main with the above. He remarks that when the slit of the spectroscope is carried across a solar spot, the relative intensity, as well as the length of the spectral lines, changes. The spectrum is never really interrupted ; it is merely darkened through the narrowing of the bright interspaces by reason of the bulging of the dark rays and the formation of a number of cloudy lines. Many of these cloudy lines correspond with those observed in the spectrum of the sun, when on the horizon ; and certain lines in the red orange space are identical with those produced by a cirrus cloud crossing the field of view, and, therefore, indicate the existence of watery vapor. A careful comparison of their spectra has led Father Secchi to the conclusion, that, as the spectra of the red orange stars and the spectra of the solar spots are identical, the sun, stripped of its chromosphere, would resemble Alpha in Orion, or Omicron in the Whale ; as it is, it is a variable star. The layer of absorbing vapor, which, by its varying thickness and density, produces this variation, is denser on the spots. The questions then arise : is it piled up at such points above the average level of the chromosphere ?—or, does it fill cavities in the photosphere ? The Rev. Father inclines to the latter opinion. He finds, moreover, that in the spectrum of the spot, the iron and calcium lines are more strongly marked than the magnesium and sodium ; hence, he concludes that the former metals, existing at the bottom of the cavity, mark the dark nucleus of the spot : the latter are within the region of the penumbra. Remark that this opinion differs materially from the old continental view, which supposed the dark nucleus to be the dark body of the sun—the penumbra to be the sides of the cavity in the chromosphere. It approaches near the old English notion that the spots are caused by a downrush of a cool, absorbing atmosphere upon the visible body of the sun,—only, according to the modern view, it fills cavities in the gaseous body of the sun. This gaseous body, under such pressure as exists there, emits white light, which is more largely absorbed in the spot than elsewhere, because there the absorbing medium—viz., the vapors and gases which fill the cavity—forms a deeper and denser layer than elsewhere.

As I said before, the subject requires further elucidation; and in its further investigation, Capt. Ashe's theory of falling asteroids being elements in the disturbance which takes place in the region of a spot, is certainly worthy of consideration; for, although the theory requires remodelling to suit new facts, some of the data on which it rests cannot be overlooked.

The old cavity theory, which he long ago showed the absurdity of, has been abandoned by all, and the new cavity theory, which is being put in its place, by no means explains all the facts of the case. At the same time, it is not easy to reconcile Capt. Ashe's hypothesis with the laws of physics and chemistry. Were the spots caused by melting asteroids floating on the chromosphere, these incandescent masses of metal would give continuous spectra, whereas the spots give the very reverse; but one cannot conceive how a mass of heavy metal could float for days upon an ocean of light hydrogen, while undergoing fusion and then volatilization; nor in a sea of burning hydrogen could there probably be formed the dross which the Captain supposes the penumbra of the spot to be. For all that, the correspondence between the zone to which spots are confined and that within which asteroids would fall upon the sun's surface, and the fact that there is a maximum and minimum period in the occurrence of sun-spots, give strong probability to the supposition that there is a relation between sun-spots and intra-mercurial asteroids.

Lockyer and Janssen's discovery has greatly detracted from the interest which attends a total eclipse, as the most remarkable phenomena of the eclipse—the chromosphere and its protuberances—may be observed at any time. This may be the reason why no European party crossed the Atlantic to witness the eclipse of the 7th of August last. A further reason, doubtless, was, that it was known it would be so carefully observed by American astronomers as to make any assistance from them almost superfluous. It is, nevertheless, to be regretted that some European astronomers, who witnessed the eclipses of 1842, 1860, and 1868, did not bring their experience to the observation of the last. The scientific results, however, of the eclipse have been by no means insignificant. All the parties of observation have not yet published their reports ; but from such as have appeared, the following summary is gathered :

The eclipse was total at sunrise in Siberia ; it crossed the north Pacific a little south of Behring Straits, and thence pursued a south-east course across the continent, terminating at sun-set off the coast of North Carolina. It was observed by two U. S. Government parties in the Pacific, whose reports have not yet been published ; by Mr. Gilman, of New York, at Sioux city, on the Missouri ; by Capt. Ashe, at Jefferson City, Iowa ; at Des Moines, about 50 miles south-east of Jefferson, by Dr. Curtis, of the U. S. Army Medical Museum, and a party from the U. S. Naval Observatory ; as well as by Prof. Rogers, and some of the officers of the U. S. Coast Survey ; by three divisions of a party under charge of Dr. Morton, of Philadelphia, stationed—one at Burlington, another at Otumwa, and the third at Mount Pleasant, Iowa. Prof. Alexander and others took up a position at Springfield, Illinois ; and the Harvard University sent their observers to Selbyville, Kentucky. Many other colleges and scientific bodies sent their representatives to these or other stations along the line of totality.

The general phenomena of the eclipse did not differ from what had been observed on previous occasions. The darkness was not so great that print of moderate size could not be read during totality; and it was not till totality had almost occurred that the decrease in light became to the eye very manifest. The moon moved majestically and calmly across the surface of the sun, till it had almost extinguished it: when, quickly, as if by an effort, it totally eclipsed it. The shadow of the moon, as it rushed through the air, and enveloped the earth in sudden darkness, struck observers with more awe than perhaps any other of the many almost preternatural appearances of the eclipse—an awe that was dissipated only by the equally sudden return of light, as the sun blazed forth from behind the jet-black orb of the moon. The planets Mercury, Venus, and Saturn, and one or two stars of the first magnitude, burst forth at the commencement of totality, and were visible for a few seconds afterwards. The sky is described (for, having been shut up in my photographic room, I saw nothing, and speak, therefore, from hearsay) as presenting a very unusual appearance. Immediately outside the sun, beyond the corona, it was of an inky black; yet, even here there were no stars visible, only the planets; while further towards the zenith, and beyond it, to the east, the color changed to an indigo blue; and all around the horizon, but particularly to the west, it was of a bright orange. At the moment of totality, there shone forth a halo of light from all sides of the dark moon; but so much more strongly from the equator than the poles, that it more resembled a nimbus, lozen-shaped, with rays of unequal length, than a regular crown of light. Some of the rays were over 1° in length. Within the corona there appeared on the eastern limb of the sun, or rather moon, a rugged line of rosy red light, rising in several places into larger masses. As the moon advanced and covered the eastern limb and this range, as it were, of burning mountains, it uncovered a similar range, with its high peaks, on the western limb, and brought into better view a like phenomenon on its lower limb. This band of red light, with its remarkable excrescences, is probably the chromosphere and its protuberances.

THERMOMETRICAL OBSERVATIONS

Were made by Professor Pickering, with the following results:—Shortly before the eclipse, the thermometer rose, attaining its maximum at the instant of contact, so that when three digits or 14 per cent. of the sun's disk was obscured, the temperature was about the same as before the eclipse. Again the thermometer began to rise after the eclipse was over. These anomalies, Prof. Pickering thinks, are explained by the photographs taken at the same time. The increased brightness which they show along the moon's limb, proves, he supposes, that the latter augmented the active power of those parts of the sun's disk nearest to it, and thus renders the increase of heat very probable. This is at least another contribution to the many explanations of this knotty point.

THE PHOTOGRAPHERS' DELINEATIONS OF THE ECLIPSE

Are many, and very beautiful.

Photographs were taken during totality by Dr. Curtis, at Des Moines; by Mr. Willard, at Burlington; by Messrs. Brown and Baker, at Otumwa; by Messrs. Jas. Clifford, Curbutt, and other gentlemen, at Mount Pleasant; by Mr. Black, of Boston, at Springfield, Ill.; by Mr. Whipple, at Selbyville, Kentucky; and by ourselves, at Jefferson. Prof. Davidson took photographic apparatus to Alaska; but we have not heard what use he made of it. Several other observers, whose telescopes were not provided with clock-work, took pictures during partial obscuration only.

At Des Moines, 120 pictures were taken during the partial, and 2 during the total eclipse. They are all faultless. The pictures before and after totality were taken at regular intervals, and carefully timed, so as to assist in the correction of nautical tables. The two pictures of totality are probably the grandest photographs of an eclipse ever taken. They are 5½ inches in diameter, and were exposed 120 and 40 seconds respectively. Owing to this lengthy exposure, the first picture exhibits the chromosphere all round, and shews combined in one picture passing phases which were not visible at any one moment. Scientifically, this is a disadvantage. It shows the most exquisite detail in the structure of the chromosphere, especially in a group of faint fantastic forms in the eastern limb, which, throwing out long tongues of light, have the appearance of delicate flickering flames, in many cases disconnected from the surface of the sun. In the second picture, the chromosphere is visible only on the western limb, and is less brilliant than that on the eastern.

By the three parties under Prof. Morton, thirteen pictures in all were taken during totality, with exposures varying from 5 to 16 seconds—all more or less successful. All display the chromosphere and protuberances, and one of them, taken the instant before totality, shews the limb of the sun cut into bright dots by the mountainous edge of the moon, settling, Professor Morton thinks, conclusively, the question of the origin of Bailey's beads. The exposure in all cases was too short to secure the corona; but this was admirably done by Mr. Whipple, at Selbyville, who exposed a plate in the principal focus for 40 seconds. Even in this picture, the chromosphere may be detected as a very bright ring within the crown of light, but all detail is smothered; for, so actinic is the light issuing from the chromosphere, that probably no picture was exposed briefly enough to catch all the detail in its structure and that of the protuberances, which the photographic plate is capable of delineating. If any attempts are made to photograph the eclipse which will occur in China this year, the aim should be by very short exposure—say one second in the principal focus,—to secure the utmost possible definition in the chromosphere. As these protuberances are ever in motion, reliable deductions as to their structure can be drawn only from pictures taken with a very short exposure.

From the rapidity which my plates—exposed only ten seconds—developed, I am satisfied a well-defined image of a protuberance can be taken in one or two seconds. So short an exposure would only give the larger masses of the chromosphere, whose light, from the great accumulation of light-giving material burning in them, is very strong; but it should suffice for giving the most minute detail in these masses —detail which is obliterated or blurred in pictures with a longer exposure.

We took four pictures, of one inch diameter, in the principal focus of the large telescope of the Quebec Observatory, which Capt. Ashe had the courage to take with him, and the skill to pack, mount, and repack, without accident. Had my lecture not already exceeded all reasonable limits, I would like to explain the ingenious mechanical contrivances by which the Captain and those in charge of other expeditions secured rapidity and regularity of exposure. Our instrument was a nine-foot equatorial, made by Alvan Clarke, of Cambridge, Mass. Our pictures received an exposure of ten seconds each, and were taken at equal distances of time from the beginning to the end of the totality. They exhibit the protuberances and parts of the chromosphere well, but do not shew a trace of the corona.

PROTUBERANCES.

It is not easy to distinguish the protuberances in all cases from the chromosphere whence they spring. Our photographs, and a drawing made by Mr. Vail, of Philadelphia, who rendered us the greatest assistance in our preparations, and carefully noted the passing phenomena of the eclipse through a Dolland 40-inch telescope, agree in laying down five protuberances. Mr. Falconer, of London, who likewise joined our party, distinguished only five protuberances. Professor Morton, on the other hand, finds nine in his pictures. Some that he and we consider as such, only differ by being isolated from the neighbouring banks of light. Flames are strongly marked in pictures taken to the east of us, of which the rudiments only are visible in ours; and the large protuberance on the lower limb, which in our pictures grows from a bright dot in picture I. to a high flame in picture III., burns down in picture No. IV. to one-half its former height, and commences to assume the flattened form which it has in all the pictures taken to the east of us. This remarkable protuberance was seen by Capt. Ashe and the other members of our party to blaze up rapidly after the exposure of the second picture; then the top of the flame was wafted away to the east, as if by a strong current in the upper atmosphere of the sun, and the body of the flame gradually burned down, assuming the forms it bears in pictures III. and IV.

Mr. Vail described the protuberances, and especially the large one, as follows:

"But the most remarkable appearance of all, and that which attracted the attention of every one who witnessed the eclipse, whether seen with the naked eye or with the telescope, were the red protuberances that shot up immediately on the disappearance of the sun from various places on the edge of the moon. Their position your photographs will fix better than I can describe. The largest was on the lower edge of the moon, and was, by my estimate, when highest, not less than two minutes in altitude from the edge of the moon, or about 55,000 miles.

"Its colour was a bright *pinkish red;* its outlines were perfectly well defined, and were not curves, but rather irregularly broken straight lines; and throughout it seemed marked by similar lines.

"It reminded me of the appearance one sometimes sees on the face of a cliff where the rock is broken by horizontal and vertical lines. The same, or nearly the same, appearance would be presented if one were to view columnar basaltic rocks from a point where the rocks in the rear would rise above those in front. I would, therefore, suggest whether these lines may not have a similar origin and each be the outline of a vast column of luminous matter thrown up above the atmosphere of the sun."

Capt. Ashe has made accurate drawings of the structure of the protuberances from the magnified photographs. No semblance of a spiral structure, such as was thought to be discernible in the Indian pictures, exists ; but dark lines cut the flame longitudinally and transversly giving it the appearance —as described by Mr. Vail—of being built of huge blocks, laid in irregular rows. The same structure may be recognized in the lower protuberance on the western limb. The outline of these flames, as delineated in the photographs, is not sharp, especially on their western side, where a hazy band, like a shadow, is very manifest. The bright band of light, broken into flickering flames, which surrounds the eastern limb, exactly corresponds to Lockyer's description of the chromosphere. It presents, however, a different structure on the western limb, where it forms a series of concentric bands, extending round the sun, from the large protuberance on the lower limb, for about 90°. Within this are included three protuberances. The axis of all these protuberances are parallel to one another, and the chromosphere is crossed by numberless lines parallel with one another and the protuberances, and not radiating from the sun's centre, but at right angles to its axis. It would be presumptuous to offer any explanation of these appearances before comparing our pictures with others, as even photographs are liable to so many sources of error.

All the prominences in our own and others' pictures seem to eat into the moon ; and the same appearance is presented by the more elevated portions of the chromosphere. Captain Ashe conjectures that this is due to reflection from the moon's surface. This is clearly proved, he thinks, by the following facts, viz.: that the limb of the moon is distinctly seen as a dividing line between the protuberance and its reflection, and that the inner is a similar and inverted image of the outer figure. The same explanation of this puzzling phenomenon has been given independently by Dr. Gould.

SPECTROSCOPIC OBSERVATIONS.

The best spectroscopic observations yet published, are those of Professor Young, who was stationed at Burlington, Iowa. He observed 9 bright lines, the number noted by Mr. Rayet at the previous eclipse, though they do not correspond in position. Two, if not three, of the lines are indisputably those of hydrogen, and several others nearly correspond with iron lines, In the following table, I give a list of the lines observed, and Professor Young's remarks. The middle column I am responsible for.

Lines Observed by Prof. Young.	Coincidences and Nearest Correspondence.	Remarks.
C.	—A hydrogen line........	Dazzling in brightnesss.
1017.5.	—Near double D—Sodium..	Bright, but not equal to C.
1250.2.	—1250.4.—Iron...........	Very faint; position only estimated, and extending apparently beyond the protuberance, and thought to be a coronal line.
1350.2.	—1351.1.—Iron...........	Like the preceding.
1474.	—1473.9.—Iron...........	A little below E; conspicuous, but not half as bright as 1017.5. Like the two preceding, supposed to extend into the corona.
F.	—Hydrogen.	Next to C in brightness.
2602.2.	—2601.7.—Iron...........	A little fainter than 1474; position determined by micrometrical reference to the next.*
2796.	—Hydrogen?.............	A little below H *g*.; in brightness, between 1017.5. and 1474.
H *g*.	—......................	Somewhat brighter than 1474.
B.	—......................	Supposed to have been overlooked.

* Professor Young has since expressed doubts as to this line.

Mr. Harkness, the spectroscopist of the Des Moines party, remarked to me that he distinguished different lines in the different protuberances, and that the spectra of the same protuberance differed at different altitudes. It will be remembered that last year M. Rayet observed 9 lines in one protuberance, and only 8 in another. These discrepancies are not difficult of explanation; for, supposing the protuberance to be caused by violent convulsions, which displace the gaseous envelope of the sun, while the lighter hydrogen which composes the outermost layer will occupy the top of the flame, the heavier metallic vapors will be lifted out of their appropriate strata, and be detected about the base of the protuberance. Suppose, further, that a protuberance on the eastern limb of the sun is examined at the instant of totality, the heavier vapors of the base and the lighter gases of the summit will both be uncovered, and give their respective spectra; whereas, if a protuberance on the opposite limb be observed, as it is being uncovered, only the summit will be visible, and the hydrogen spectrum alone be obtained, till just before totality finishes, when the base of the protuberance comes into view.

The chromosphere appears to be heaped up most densely about the equator, though the largest protuberance in each of the late eclipses was isolated and at a distance from the equator.

THE CORONA,

As previously stated, has been brought out in only one photograph, which was taken by Mr. Whipple. It is a very remarkable picture. The corona resembles what it appeared to the naked eye, an irregular, somewhat oval-shaped halo of light, lowest at the poles, but at the equator one-fourth of the sun's diameter in height; diminishing in intensity from within outwards. The rays which to the eye seemed distinct and in constant motion, like cilia, form in the photograph, of necessity, from the length of exposure, an unbroken sheet of light. Prof. Hume describes the structure of the corona as "fibrous, slightly crooked, or twisted, somewhat like a cirrous cloud, and of silvery whiteness."

We saw that the Indian observers disagreed as to the spectroscopic character of its light, M. Rayet finding no spectrum, and Major Tennant a continuous one. Prof. Young thinks it gave a faint, continuous spectrum, and that three of the lines, viz.: 1250, 1350 and 1470, which he found in the protuberance spectrum, extend into the corona, and that these three are the lines which Prof. Winlock detected in the spectrum of the aurora borealis. Prof. Young is, however, not confident of the accuracy of his observation, and thinks it possible that the three lines in question may extend only beyond the more visible parts of the protuberance into that hazy region which the photographs dimly reveal, as if it were a shadow thrown by the flame. These three lines are not exactly coincident with any known lines, though they vary very little from three iron lines. May they, therefore, not belong to some unknown element—a gas, lighter than hydrogen, and which, like the hypothetical ether, fills space? We can hardly suppose such intense action as exists on the surface of the sun to be unaccompanied by electricity, which, in the auroral light of our own heavens and the corona of the sun, may render this hypothetical gas luminous. Storey, years ago, discussed the likelihood of such an extra-atmospheric medium. If Prof. Young's observations are corroborated by those of others, there may be found some probable proof for such a supposition.

POLAROSCOPIC OBSERVATIONS.

Professor Pickering entirely disagrees with the observers of the Indian eclipse as to the polaroscopic condition of the coronal light. He says:—"The form of polaroscope used was that adopted by Arago in his experiments on sky polarization. It consists of a tube about 20 inches long and 2 inches in diameter, one end of which is closed by a double-image prism of Iceland spar, and the other by a plate of quartz. Looking through the former, we see two images of the latter, which, when the light is polarized, assume complementary tints. If, now, the corona was polarized in planes passing through the centre of the sun (as is generally admitted), when viewed through the polaroscope, in one image the upper and lower parts should have appeared blue, and those on the right and left yellow; while in the second image these colours would be reversed, the yellow being alone below, and the blue on the sides. In reality the two images were precisely alike, and both pure white; but one was on a blue, and the other on a yellow back-ground. From this we infer that the corona was unpolarized, or at least that the polarization was too slight to be perceptible." Professor Pickering adds, that "although this does not prove that it shines by its own light, since polarization is produced only by specula, and not by diffused reflection, yet, these observations and those by the spectroscope seem to render it probable. This view is also strengthened by the fact, that as the most distant portions are but about 100 parts the distance of the earth, they receive about 10,000 times as much heat per square foot. The coloured back-ground mentioned above, shews that the sky, close to the corona, is strongly polarized; and since the tint is uniform on all sides of the sun, the plane of polarization is independent of the position of the latter—that is, the same on the sides that it is above and below it. The most probable explanation of this most unexpected result, is, that the earth beyond the limits of the shadow, being strongly illuminated, acts as an independent source of light, and this being reflected by the air, becomes polarized in planes perpendicular to the horizon." These results are so diametrically opposed to those previously obtained, that their accuracy is sure to be called in question.

The discrepancies in opinion of the different observers of the corona, in the late eclipses, are in striking contrast to the accordance of their observations of the protuberances. To the corona attention must chiefly be directed in future,—the main points as to the constitution of the protuberances having been determined. No means of examining it, except during an eclipse, have yet been proposed; so that unless some method of doing so is devised in the interim, we must wait for the intervention of the moon before we can be sure what that beautiful crown of light is—whether it is composed merely of the rays which issue from behind the moon as we see them radiate from behind a cloud when it obscures the the sun; or whether they emanate from some metal known or unknown, forming an extremely attenuated atmosphere beyond the hydrogen envelope; or whether they are identical with the auroral or the zodiacal light, whatever they may be.

NOTE ON THE CORONA.—Among the many theories suggested to account for the corona, I have not seen revived Meyer's hypothesis as to the origin of the zodiacal light. In his essay, "On the Dynamics of the Heavens," he says:—"As cosmical masses stream from all sides in immense numbers towards the sun, it follows that they must become more and more crowded as they approach thereto. The conjecture at once suggests itself, that the zodiacal light, the nebulous light of vast dimensions which surrounds the sun, owes its origin to such closely-packed asteroids. However it may be, this much is certain, that the phenomenon is caused by matter which moves according to the same laws as the planets round the sun; and it consequently follows that the whole mass which originates the zodiacal light is continually approaching the sun and falling into it. This light does not surround the sun uniformly on all sides,—that is to say, it has not the form of a sphere, but that of a thin convex lens, the greater diameter of which is in the plane of the solar equator; and consequently it has, to an observer on our globe, a pyramidal form. Such lenticular distribution of the masses in the universe is repeated in a remarkable manner in the distribution of the planets and the fixed stars."* May the zodiacal and coronal light be one and the same? Supposing the above hypothesis to be correct, would not the asteroids faliing in a shower towards the snn by their attrition produce a sheet of light resembling the corona? Moreover, as the meteors which fall upon our earth are composed almost entirely of iron, we may suppose those reaching the sun to contain that metal as a predominant element. Although the spectroscopic observations of the corona differ—Professor Young having detected three bright lines, and Professor Harkness only one,—by both the presence of iron is rendered highly probable.

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* Page 272 of Youman's "Collection of Essays on the Correlation and Conservation of Forces."