1. **The** dispersion, absorption, and diffusion of light, are effects, the complete solution of which, it may be assumed, is still very distant from us. Thus the explanation given by Cauchy, in conformity with the notions of Fresnel, that the sphere of attraction of the molecules is comparable in magnitude with the length of undulation, has not yet been applied to doubly refracting bodies; and so far as Cauchy's theory has reference to isophanous bodies it also needs completion, inasmuch as the action of the medium itself is not taken into account. Further, as regards the phenomena of absorption, there is certainly no lack of explanations, but the difficulty is to apply them in each particular case; and, as several causes work together, to appropriate to each its due proportion in the production of the phenomena to be explained. The grounds more particularly referred to in the explanation of the absorption and diffusion of light, are the following:—

a. An unsymmetrical distribution of the molecules of the medium, the consequence of which is, that in the differential equations for the motion, differential coefficients of an uneven degree are introduced. As far as I know, this cause was first assigned by Cauchy in a letter to Libri.

b. The principle adduced by Euler in his *Theoria Lucis et Caloris*, according to which the colour of a body is produced by the resonance of the oscillations, which can be assumed by the particles themselves.

c. The interference of light. On this principle Newton is known to have based his celebrated theory of colours, which was further expanded by Biot in the spirit of the theory of emission. M. von Wrede was the first to apply it in the sense of the theory of undulation, by showing that the phenomena, in the case of absorption by gases, &c., might be referred with ease to the principle of interference.

Now with regard to the first of the three grounds of explanation, it alone is by no means sufficient to explain the phenomena of colours. That in general the opacity of bodies might be referred to it as a cause is easy to discern; but it does not explain why a certain colour, to the exclusion of all others, is produced.

The principle of Euler also explains, not so much the colour which a body actually exhibits, as that which it is unable to assume, because most of the oscillatory motions which bodies assume in

* From Poggendorff's *Annalen*, vol. xciv. p. 141.
M. A. J. Angström's Optical Researches.

consequence of absorption, make no impression on our organs of sight, but generally fall in the domain of feeling.

If therefore the colours of bodies are to be explained by resonance, this property must also be ascribed to the ether, and thus we arrive with ease at the third of the principles referred to, namely to that of interference.

2. It is necessary to distinguish strictly the absorption of light from its diffusion. Both, indeed, produce the common result of weakening the passing rays; but they differ from each other essentially in the circumstance, that the diffused light possesses the same properties as the incident light; the absorbed portion, on the contrary, exhibits itself as heat, or as a chemical agent; in other words, in the former case the time of oscillation is unchanged, but in the latter this is not the case. This is an essential distinction, which has not always been borne in mind in optical investigations, although Melloni proved it long ago in the case of heat. That the diffused light possesses the same properties as the incident light is most evident from the fact that the lines of Fraunhofer, in the solar spectrum, are also exhibited by the light of the planets, and by all bodies illuminated by the sun. This is not disproved by the newest investigations of Stokes, in which he seeks to show, that, in the case of absorbed light, the time of vibration is altered, because the facts there brought forward belong to the latter class.

Diffused light must therefore, according to the foregoing, be produced by modifications of the undulatory motion of the ether itself, while absorbed light is transferred to the molecules of the body. These are thereby moved from their positions of equilibrium and thrown into vibrations, which vary with the peculiar characteristics of the body. It is, however, to be well borne in mind, that a medium absorbs, not only those vibrations which it most readily assumes, but also those which occupy a simple relation to its own time of vibration, such as the octave, third, &c. As bodies in general are not luminous, it follows that the absorbed light must escape the cognizance of the eye.

That this, however, is not always the case, is proved by Brewster's remarkable discovery in the case of the alcoholic solution of the green colouring matter of leaves. When a beam of light is transmitted through such a medium, the liquid in the path of the beam is coloured blood-red by unpolarized light. This phenomenon, to which Brewster has applied the name of inner dispersion, furnishes a manifest proof that the absorbed light does not always pass to oscillating series of a lower order. The so-called epipolarized rays of Herschel belong to the ordinary case, in which the absorbed light reappears as heat, to the extent that here it is chemical rays which are absorbed, and which,
according to Stokes, produce the luminous effects discovered by Herschel.

3. Now, as according to the fundamental principle of Euler, a body absorbs all the series of oscillations which it can itself assume, it follows from this that the same body, when heated so as to become luminous, must emit the precise rays which, at its ordinary temperature, is absorbed. The proof of the correctness of this proposition is, however, surrounded with great difficulties; for the condition of the heated body, as regards elasticity, is altogether different from the state in which the light is supposed to be absorbed. An indirect proof of the truth of the proposition is furnished by the connexion, discovered by M. Niépce de Saint Victor, between the colour imparted by a body to the flame of alcohol, and that developed by light upon a disc of silver which has been chlorinized by the body under consideration. As the disc of silver, treated with chlorine alone, assumes all the tints of the solar spectrum, and, when treated at the same time with a colouring body, exhibits almost exclusively the colour of the latter, this cannot occur otherwise than by the exclusive absorption on the part of the so-prepared silver disc of the precise tint which belongs to the colouring body.

4. One of the most convenient and most practicable means of studying a glowing body is presented by the electric spark, although the body in this case is probably in the gaseous condition. I have therefore believed that an investigation of the spectra obtained from electric sparks drawn from different metals would not be without interest for the theory of light. The subject has been already treated by Wollaston, Fraunhofer, Wheatstone, and lastly by Masson, in a memoir in the Annales de Chimie et de Physique, 1851. Masson has also measured the electric spectra of various metals, and has drawn them by means of the Camera lucida. Nevertheless I venture to hope that the present investigation will not be deemed superfluous, when the results obtained by me are compared with those obtained by my predecessors.

I have found that the spectrum of the electric spark must really be regarded as consisting of two distinct spectra; one of which belongs to the gas through which the spark passes, and the other to the metal or the body which forms the conductor.

The electric spectrum is traversed,—1. By a multitude of luminous lines, comparable in number and distribution with the lines of Fraunhofer in the solar spectrum. These lines are the same for all metals, but vary in intensity with the strength of the condenser, and the greater or less humidity of the air. The nature of the conductor does not appear to exercise any
other influence than that some of its own lines render, by their brightness, some of the others less perceptible.

2. By shining lines peculiar to each metal. These lines are easily distinguished from the foregoing by the fact, that when the condenser is not altogether too strong, and consequently the charge too feeble, they do not form complete transverse lines, but appear to proceed from both edges of the prism, and to be extinguished before they reach the centre. They are no less distinguished from the former lines by their brighter light, and seem, as it were, to stand forth against the dull ground on which the said lines are drawn in undiminished intensity through each point of the transverse section. This predominating brightness, particularly with strong charges, is doubtless the reason why Masson, in all the spectra which he has drawn, has not found more than four lines identical.

To explain the production of the first spectrum, I assume with Faraday and Masson that the electric spark is produced by a current which propagates itself across, and by means of, ponderable matter, which it heats in the same manner, and according to the same laws, as a voltaic current heats a metallic wire. The other spectrum, on the contrary, is produced by the heating and dispersion of the particles of the conductor which proceed simultaneously from both the poles, but on the way lose both their temperature and their luminous properties.

Among the constant lines there are two which were observed by Fraunhofer, and which exceed the others in brightness, namely, a double line in the yellow and one in the green light. In Masson's discovery, and also here in fig. 1, Plate II., they are denoted by γ and δ*. It is possible that these two lines are sometimes common to both spectra, and that their brightness is thus increased; I will not venture to deny this. In the case of bismuth, at least, this is the case with the line γ.

To render the comparison between the solar spectrum and that of the electric spark more evident, I have drawn both of them, side by side, in fig. 1. Both drawings are made from nature, an angle of one minute embracing a millimetre and a half of the drawings. The difference between the spectra is, that to form a correct notion of the upper or electric spectrum, the black lines must be regarded as luminous ones; luminous with the colour which corresponds to their position in the spectrum. For these observations, a flint-glass prism of Merz, with a refracting angle of 46°34'57", was made use of.

The observations on which the drawing of the electric spec-

* In Masson's memoir, however, the line δ for antimony is incorrectly given; in like manner the line β, which is in general very weak, is in the case of copper confounded with the line which I call D.
trum is based are contained in the following table. It is to be remarked, that the measurements for the different metals were not determined at once, but that the prism was so fixed for each series that the line D gave the minimum of deflection.*

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In order to calculate the indices of refraction, and from them the wave-lengths which correspond to the principal lines of the spectrum, I have measured the absolute deflections of some of them; two spheres of zinc served as conductors.

a.  

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<td>Δ=34 0 48&quot;</td>
<td>Δ=34 21 22&quot;</td>
<td>Δ=34 30 50&quot;</td>
<td>Δ=34 52 45&quot;</td>
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The observations for the position b of the prism were made between the double readings which correspond to the other position a.

Two corresponding readings gave for the lines of Fraunhofer, D and δ, of the solar spectrum,

D . . . . Δ=33 51 40"  

* A circumstance which interferes with the accuracy of the measurements is due to the fact that the sparks do not always spring from the same point. This may be prevented by coating the balls with a layer of wax. The first spark bursts the coating, and all the succeeding ones follow in its path.
that is to say, values which are nearly equal to those of D and E in the electric spectrum.

A direct experiment nevertheless showed that D in the electric spectrum does not completely coincide with the vivid yellow line formed in the spectrum of the flame of alcohol, but lies somewhat nearer to the red. The yellow line coincides with the line to the left of D which is common to all the metals, and which I have denoted by n in fig. 2, Plate II.

5. When the solar spectrum is compared with the electric one, it is found that some of the lines, such as C, D, E, G, and we may also say H, have their corresponding lines in the solar spectrum; but for the strongest, γ and δ, this is not the case.

A complete correspondence, however, between the solar and the electric spectrum is the less to be expected, as the lines in the former, as is generally assumed, are not only due to the action of the atmosphere, but also to be referred to the action of the sun itself. For the present we are not in a position to separate the two systems of lines from each other, although Brewster’s numerous researches on the peculiar influence of the atmosphere have furnished interesting results. Thus the atmosphere produces dark lines on the violet side of C, and on the red side of D; in like manner is produced, on the other side of D, a wide band, possibly in the neighbourhood of γ, &c.

Miller states that during an approaching thunder-storm he has seen dark lines between D and C, but nearer to D, which would seem to coincide with the line γ. In Broch’s drawing of the solar spectrum, taken as the sun was near rising or setting, a dark zone also occurs near D, although the distance from D appears to be smaller than that between γ and D. Between F and G is a dark zone, which possibly corresponds to the line F in the electric spectrum.

The analogy between the two spectra may, however, be more or less complete when abstraction is made from all the minuter details. Regarded as a whole, they produce the impression that one of them is a reversion of the other. I am therefore convinced that the explanation of the dark lines in the solar spectrum embraces that of the luminous lines in the electric spectrum, whether this explanation be based upon the interference of light, or the property of the air to take up only certain series of oscillations. The first view has only one difficulty, and that is to explain how the different retardations, which are necessary for the effect, are produced; this will be the more difficult for the electric spectrum, inasmuch as all these retardations must occur in the inconsiderable mass of air which is in direct contact with the electric current.

6. In fig. 2 I have given a sketch of the principal lines
M. A. J. Angström's *Optical Researches.*

which exhibit themselves in spectra of different metals. That by the use of stronger charges, particularly with the metals which melt at high temperatures, such as platinum and iron, other lines may appear, is probable; I believe, however, that I have omitted none of the more important ones. The simple inspection of the figure shows, however, a great regularity in the distribution of the lines; also, in the case of some metals, a certain tendency to appear in groups. In this manner they show themselves with lead, particularly in the yellow and blue-violet field; with zinc in the red and blue; with bismuth several distinct groups are formed. In general, with the more fusible metals the lines seem to spread themselves more. With mercury and lead the longest go into violet. It is singular that gold and silver have a common line in green; but besides this, silver has a few common with mercury.

To all the metals the line $n$ is common; also the line $m$ in red, although in consequence of its feebleness it is difficult to determine its position with accuracy, seems to be common to all; with mercury, however, I did not see it. Coal gave no lines, except those which were to be found in all spectra.

7. Wheatstone has observed that when the poles are formed of different metals, the spectrum contains the lines of both. It was therefore interesting to examine whether a compound of the same metals, particularly a chemical one, would also exhibit the lines of both metals, or distinguish itself by the exhibition of new lines. The first was found to be the case. The only difference observed was, that certain lines were absent, or showed themselves with greater difficulty; but when they appeared, it was always at the same places corresponding to the single metals. It is easy to convince oneself of this when one pole is formed, for example, of Sn$^4$Pb. From the side of the spectrum which corresponds to the chemical compound, lines proceed which belong to both metals, and the position of these lines may be controlled by making use of both metals successively for the opposite pole.

If the metals are combined in other proportions, no difference appears. With Zn Sn the lines in blue were displaced a little towards the violet, but very inconsiderably. This result is so far of interest for the theory, as it shows that the particles of both metals are not united in particular groups, but that each forms distinct centres of oscillation.

8. It does not seem that the lines peculiar to each metal in the electric spectrum can be due to interference. By interference lines of sharp outline cannot be produced except when they lie very near each other, otherwise they spread themselves over a larger portion of the spectrum. Through the union of unequal retardations, groups of fine lines may certainly be formed, but
not well isolated lines. What pronounces particularly against the assumption referred to, is the fact that these luminous lines seem to proceed from the edge of the prism, and to lose themselves in the centre, while the ground on which they exhibit themselves does not appear to be in the slightest degree changed.

In the same manner as we assume that the almost homogeneous light emitted by a flame of alcohol is due to the fact that its oscillations belong almost exclusively to the yellow light, although a trace of luminous lines appears on the rest of the spectrum also, we seem, on the other hand, to be forced to assume that the bright lines belonging to a metal in the electric spectrum, the number of which increases with the strength of the electricity, correspond to the vibrations of the metal in the gaseous condition.

9. In connexion with the foregoing, I will here mention an observation which I have made on the flame of a solution of iodine in alcohol. The alcohol flame alone gives a spectrum shown in the following figure:—

\[
\begin{array}{cccc}
  b & c & d & a \\
\end{array}
\]

where \(a\) denotes the vivid yellow line, \(b\) a weaker one in the extreme blue, and \(c\) and \(d\) traces of two other lines. The solution of iodine produces, on both sides of \(d\), several bright lines with equal intervals; their distance apart amounts to about 10'. Twice, when the wick was furnished with iodine, I saw dark bands formed between \(b\) and \(c\), which appeared to be at about the same distance from each other. The phenomenon seems to be the same as in the case of the absorption by iodine; the bands were not sharply defined, but resembled real bands of interference.

10. The study of the spectra of the electric spark, it seems to me, can also contribute to the solution of a question equally interesting to both astronomy and optics. Doppler has endeavoured to explain the colour of the double stars by the assumption that the velocity of a body has an influence upon its colour. On the other hand, Petzval, in a discourse before the Academy of Sciences in Vienna, has proved analytically that the motion of a medium can have no influence on the time of oscillation, on which alone the colour depends. Although this proposition is probable in itself, still a practical proof of it is not, I think, without interest.

From Wheatstone's researches on the velocity of electricity,
we know, not indeed the actual velocity of the spark, but at least a limit value, under which it cannot fall. He found that a spark, 4 inches in length, passed in a less time than the millionth part of a second. But a stream of light 6 feet long, in a glass tube partially exhausted, showed itself also unchanged in the rotating mirror; and as, according to Masson, the spark cannot otherwise propagate itself \textit{in vacuo} than by the particles from the poles themselves, it would follow that at least 3 feet were passed over in less than the millionth part of a second. This gives a velocity which in all probability far surpasses that of the double stars.

Now, if a spark be permitted to pass in an oblique direction, according to Doppler's theory the colour of the particles which stream out from one of the poles must be different from that of the particles which stream from the other; the more so, as they move in opposite directions, the velocity above mentioned being thus doubled as regards the production of the colour. Such a difference, however, is not observed. The bright lines correspond to each other perfectly as before. Hence, from both practical and theoretical grounds, we are justified in concluding, that time of oscillation and colour are independent of the velocity of the medium from which the light emanates.

11. In the foregoing pages I have shown that the spectrum of the electric spark is really to be regarded as an overlapping of two spectra, one of which belongs to the metal, and the other to the air through which the spark passes. From this it necessarily follows, that when the spark passes through a gas different from atmospheric air, the spectrum must exhibit a corresponding alteration. Partly to ascertain the nature of this alteration, and partly to place the fact of a superposition of an air and metal spectrum beyond all doubt, I have observed the phenomena exhibited by the electric spark in different gases. The gases which, up to the present time, I have had an opportunity of examining are,—oxygen, carbonic acid, nitric oxide, hydrogen, carburetted hydrogen and nitrogen. As the results obtained appear to me to be not without interest, I take the liberty of adding them to the foregoing.

The apparatus made use of in these observations is shown in fig. 4. It consists of a glass tube and two brass caps, the whole forming a closed cylinder, in which the electric spark passes between the two spheres of brass \(a\) and \(a\). One of the brass balls can be raised or depressed by means of a screw. The tube \(\delta\) serves for the introduction of the gas, which then issues through a hole in the opposite end of the cylinder. To ensure that the cylinder contained no atmospheric air, the gas was generally permitted to stream for an hour through the vessel before the
observations began. I made use of the same flint-glass prism as before, so that the results obtained, strictly speaking, are only valid for those kinds of light for which the flint-glass is diaphanous. This is the more necessary to be mentioned here, as it is easy to forget how much glass in general absorbs the extreme ends of the spectrum. I must also mention that the gases made use of were not perfectly pure, although I do not believe that an erroneous result could be produced by the impurity present; the reader will be able to infer this from the statement of the manner in which the gases were prepared.

12. Oxygen.—The gas was obtained from chlorate of potash, and was introduced directly into the apparatus. The spectrum obtained in this instance is shown at O, fig. 3. If this spectrum be compared with that of the atmosphere, it is seen,—1st, that the strongest lines of the air spectrum, which in fig. 1 are denoted by γ, δ, D, E, have disappeared; and 2nd, that the blue and violet field exhibit new lines which do not appear in the other case.

With regard, further, to the metal lines in the case of copper and zinc, they were almost imperceptible at the end of the experiment. This was particularly the case with the zinc in the blue field. From this it seems that we may conclude, that the bright lines corresponding to the metal are not produced by the oxidation of the latter, for if this were the case, they must show themselves strongest in oxygen. Nevertheless the surface of the brass spheres showed that an oxidation had taken place, and it is possible that the cause of the phenomenon alluded to is to be sought here.

13. Carbonic Acid.—The gas was prepared in the ordinary way by means of sulphuric acid and chalk, and was carried, for the purpose of drying it, through a bottle filled with pumice-stone which had imbibed sulphuric acid. The spectrum obtained is shown at CO² in fig. 3; it resembled perfectly the spectrum of oxygen, as far as the strong lines in the blue and violet are concerned. Some difference was, however, observed in regard to the weaker lines; a bright band, corresponding to 13, fig. 1 of the air spectrum, was also observed, which did not appear in the oxygen spectrum. Nevertheless both spectra might be regarded as identical. This is easily explained by the fact, that, according to Berzelius, the electric spark decomposes the carbonic acid into carbonic oxide and oxygen, and the latter gas produces its own peculiar lines in the spectrum.

As it was possible that the violet and blue lines in the oxygen spectrum, and in that of carbonic acid, might have been produced by the oxidation of the metallic particles during their motion through the gas, and as, if this were the case, they must disappear if an
unoxidizable metal were made use of, I had the two spheres thickly girt (with mercury gilding) and repeated the experiment with carbonic acid. There was no alteration of these lines, which I regard as belonging to the gas. The lines of the metal had, however, been changed, but without becoming quite like those observed in former instances with gold. A luminous band, broken in the middle, showed itself in the oxygen spectrum three lines higher, which corresponds to F in the air spectrum, without, however, coinciding with one of the zinc lines. Besides this, at 5 and E fine lines were observed.

14. Bisoxide of Nitrogen, NO₂.—A mixture of sugar and dilute sulphuric acid was heated, and the developed gas was conducted, first through water, and then through the drying bottle before mentioned. The spectrum of the gas showed a union of the air and oxygen spectra, although by no means complete. As, according to Berzelius, the electric spark decomposes the nitric oxide into nitrogen and nitrous acid, or more probably hyponitrous acid, the two lines γ and δ must belong to the nitrogen. It is more difficult to explain the production of the oxygen lines, if we do not assume that the nitrous acid is still further decomposed.

15. Hydrogen.—This gas was produced from zinc and sulphuric acid, being dried in the ordinary manner. The spectrum is shown at Hₐ and Hₜ in fig. 3. Hₜ represents, in an approximate manner, the luminous intensity of the different parts of the spectrum. Remarkable, in the case of hydrogen, are the strongly luminous and wide lines at the red end of the spectrum, which, moreover, besides a feeble line in the vicinity of the former, contains only two bright portions, one at the limit of blue and green, and the other in the extreme blue.

In general the hydrogen spectrum bears a great resemblance to that of the flame of alcohol, only the red lines must be conceived to be moved nearer to the yellow light. The facility with which hydrogen transmits electricity is remarkable. When the spheres were almost 2 inches asunder, the sparks passed with the greatest ease.

16. Carburetted Hydrogen, CH.—This gas was developed from alcohol and sulphuric acid, then conducted through a solution of potash, and afterwards through the drying apparatus. The spectrum was nearly the same as that obtained with hydrogen, and for this reason I have not drawn it. It was however brighter, particularly in the green, and also showed to the left of E, fig. 1, a bright line, which I did not find in the hydrogen spectrum. As the electric spark decomposes carburetted hydrogen into its elements, this result is not to be wondered at, particularly as coal exhibits no lines peculiar to itself in the spectrum.

17. Nitrogen.—It follows from what has gone before, that the bright lines in the air spectrum belong almost exclusively to the nitrogen. To submit this conclusion to a direct test, I enclosed a stick of phosphorus in the apparatus and ignited it by means of a heated copper wire, introduced through the small opening which permitted the issue of the gas. The aperture was then closed. The nitrogen thus obtained is not pure, but is mixed with a white smoke of phosphoric acid; this, however, falls and leaves the nitrogen alone behind. *The electric spark showed the same appearances as in atmospheric air.* This result not only corroborates the conclusion already referred to, but it also shows that the presence of the phosphoric acid does not produce any change, and that the air spectrum cannot be regarded as the result of the combustion of oxygen and nitrogen.

18. Another question follows:—Is the glowing of the gaseous particles produced by the propagation of the electricity, or is it a purely mechanical consequence of the motion of the metallic particles? The latter appears to be principally the case. When, for instance, the sparks pass between two points in the same horizontal plane, the metallic particles will nevertheless be scattered vertically, and the lines γ, E, δ appear as in a, fig. 5. Hence we see that the glowing of the air particles is strongest in the direction in which the metallic particles are scattered, and that both directions commingle, as it were, in the centre. It is remarkable, also, that the metallic particles show no tendency whatever to combine with each other. Thus, for example, on one occasion the zinc lines appeared on the blue, as at b, fig. 5, without any sensible change being produced in the air spectrum. The latter observation seems, however, to be opposed to the foregoing, and hence to leave the question in respect to glowing unanswered. A further contribution to its solution is furnished, I believe, in what follows.

In experiments with the sulphurets, for example with sulphuret of silver and sulphuret of antimony, when the same charge was used, two kinds of sparks showed themselves alternately, one stronger than ordinary, the other much weaker and of a dull red appearance, but so that at the surface of the metal itself it possessed its ordinary character. Regarded through the prism, the spark produced at the edge of the spectrum some bright points, but beyond this the field was dark. I placed the prism at a distance of only 4 feet from the spark, but in this case also the field was so dark that it was not possible to determine directly the position of the bright points. Only by the circumstance that now and then stronger sparks showed themselves, was such a determination possible, and it was thus found that the bright points corresponded exactly to the lines peculiar to the metal,
which here showed themselves upon the surface of the metal only. It seems, therefore, that in this case the air alone transmitted the electricity, but did not impart to the ordinary spectrum a sufficient strength of light, because the metallic particles did not by their motion cause the particles of air to glow. It would be well, however, to make this the subject of further investigation. To the same portion of the subject belongs probably a fact which I have several times observed, namely, that when one of the poles is formed of a fluid, of sulphuric acid for example, the lines in the corresponding half of the air spectrum are much weaker than in the other.

19. The experiments which I made with different metallic sulphurets led to no remarkable result. In general they gave the composition of the metal more or less completely. There was no difference observed, whether the sulphuret received from the apparatus positive or negative electricity. As examples, I have given in fig. 2 the spectra for the sulphuret of lead and sulphuret of iron. The latter, however, is distinguished by the fact, that in the vicinity of the line $\gamma$, and also in violet, bright lines are shown which were not observed in my experiments with iron. These lines could not, however, belong to the sulphur, because they must then exhibit themselves with other metallic sulphurets.

Sulphur, like carbon, seems to have no peculiar lines. I have made the experiment, not only with charcoal, but also with graphite, and have obtained no lines which could be regarded of the same character as those exhibited by the metals. The lines of the air spectrum, indeed, particularly in the violet, appeared stronger than ordinary; and in several of the bright portions fine lines were plainly visible (e. g. at H, fig. 1), but I have had no reason to conjecture that these lines belong to the carbon, particularly as platinum also shows the violet end of the spectrum in a peculiarly manifest manner. The deportment must be referred to the fact, that the coal particles, by their finer division, set more easily the air particles in a glow.

20. Summing up the observations on the spectra of gases, it follows that, in the oxygen spectrum, the greatest number of bright lines occur in the blue and violet; in the nitrogen spectrum, in green and yellow; and in the hydrogen spectrum, in red. These phenomena must necessarily be connected with the chemical and thermic properties of the gases. Regarded from the theory of undulation, the chemical activity must exert itself chiefly in the motion of the molecules; and it may be assumed with some probability, that two bodies, whose vibrations are isochronous, may combine more easily than two others. In this way the possibility of a combination is finally referred to the
possibility of exciting in two bodies coincident molecular vibrations, where under ordinary circumstances such do not exist.

The chemical activity belongs, nevertheless, to a certain class of rays. Becquerel states, "que chaque substance sensible voie le rayonnement à sa manière," and this is capable of very extensive application. Thus hydrogen, in contact with spongy platinum, is thrown into a condition in which it can enter into combination with oxygen; and the blue colour of sunlight excites in chlorine the power of entering into union with hydrogen. These blue rays act also most powerfully on the solid constituents of plants, while the yellow rays have most to do in producing the green colour, and so on. Hence there are no rays in the solar spectrum which do not possess a chemical power, although the violet end of the spectrum, on account of the part acted by oxygen in most chemical changes, shows itself here most influential. Further, the combustion of most bodies and their combination with oxygen produces a blue flame; zinc has a great affinity for oxygen, and nitrogen a feeble one; and all this seems to speak in favour of the above coincidence in the motions of vibration, which I have stated to be a condition of chemical combination, and proves at the same time that the oscillations of oxygen belong more particularly to the blue and violet portions of the spectrum.

That isomeric bodies possess different chemical properties seems also natural, as a change of position of the molecules must of necessity be accompanied by other vibrations.

21. It is more difficult to explain how, in some cases, a moderate heating calls chemical action into play; for the electric relations of the medium cannot thereby have suffered changes so considerable as to produce new series of oscillation; or, in other words, how it is that one and the same kind of oscillation, simply by increasing its intensity, is capable of producing quite different effects. This phenomenon seems to be explicable in the following manner:

Let $\xi$, $\eta$, $\zeta$ be the coordinates of a molecule with reference to its position of equilibrium, and let them be supposed to be so small, that, in the differential equations for the motion, their higher powers may be neglected. For a certain kind of motion $n = \frac{2\pi}{\tau}$, we may then set

\[ \xi = a \cdot \cos (nt + \lambda) \]
\[ \eta = b \cdot \cos (nt + \lambda) \]
\[ \zeta = c \cdot \cos (nt + \lambda). \]

Let the amplitudes be now supposed to increase, so that finally $\xi^2$, $\eta^2$, $\zeta^2$ become sensible; in this case I have found that
the equations of motion will be satisfied by the following assumption:—

\[ \xi = \epsilon + \alpha \cos (nt + \lambda) + \alpha \cos 2(nt + \lambda) \]

\[ \eta = \epsilon' + \beta \cos (nt + \lambda) + \beta \cos 2(nt + \lambda) \]

\[ \zeta = \epsilon'' + \gamma \cos (nt + \lambda) + \gamma \cos 2(nt + \lambda), \]

so that a simple augmentation of the amplitudes can excite vibrations of a higher order, which in their turn can produce chemical effects.

22. A question of great interest, to the solution of which, however, great difficulties oppose themselves, is the following:— Why is it that the spectrum obtained from the glowing metallic particles of the electric spark exhibits only certain colours, and does not, like the glowing metal itself, show all colours in a continuous series? A glowing platinum wire gives a spectrum without shining lines; the electric spark from platinum gives such lines in numbers. Not without some hesitation as to whether I have hit upon the true cause of this difference, do I venture upon the following explanation.

The general theory of small motions teaches us that the number of the molecular motions of a body amounts to thrice the number of molecules within the sphere of attraction; and from this it follows, that when the number of the molecules is infinite the number of their motions must also be infinite, and hence the spectrum must exhibit itself as a continuous whole. This, however, is not necessarily the case with the metallic particles which are scattered by the electricity. These particles may, in magnitude, remain considerably under the sphere of attraction of the molecules; by this the number of the possible oscillations becomes limited, and hence also the spectrum cannot form a connected whole.

23. I have had only recently an opportunity of becoming fully acquainted with the interesting memoir of Stokes "On the Change of Refrangibility of Light." I see with satisfaction that Stokes's explanation of the remarkable phenomena of dispersion in the green colours of plants, in sulphate of quinine, and in an infusion of horse-chestnut bark, namely, that the medium, when illuminated by the sun, becomes itself luminous, is exactly the same as that which I have given in the foregoing pages of the same phenomenon.

24. The law at which Stokes has arrived is, that in the case of inner dispersion, the refrangibility of the incident light is changed, being generally diminished; or, what is the same, that the time of oscillation of the dispersed light is, in comparison with the incident light, augmented. This law is by no means opposed to dynamical principles. The unchangeability of the
time of oscillation is only true of wave motion; and as long as
the luminous ray exists in this form, the time of oscillation is
unchanged. When, however, it is absorbed by a medium, the
particles of which are thereby set in vibration, the wave motion
passes into a pendulum motion, and the law of unchangeability
ceases to be true. The molecular motions, however, communi-
cate themselves to the aether, and a new wave motion is thus
generated, which, as regards the time of oscillation, is different
from that of the incident light, but the same as that of the pen-
dulum motion from which it originates.

As before remarked, we have long possessed in the absorption
of calorific rays an example of a similar change. Between the
dispersed light and the absorbed heat there is, however, an im-
portant difference; the former ceases with the illumination, the
latter not. What can be the cause of this difference? It is dif-
cult to answer with certainty. But the reason is probably to
be sought in the circumstance, that the substances under exami-
nation do not possess any capacity of conduction for colours
similar to their conductivity for heat; so that the molecular
motions of the medium are immediately transferred to the aether,
and become dispersed in the real sense of the term. It is also pos-
sible that the molecular motions produced by the action of light
are not infinitely small, and hence, in accordance with what has
been adduced, a higher order, such as the octave, may be com-
municated to the aether-vibrations as long as the body is illu-
minated, but that on the withdrawal of the latter they become
insensible. In such a case the medium would, however, have its
temperature increased.

Stokes also assumes that the molecular motions of the absorb-
ing medium are not infinitely small, but he draws from this the
conclusion, that the periods of motion of the medium are longer
than the aether waves which produce them, while according to
my investigation exactly the opposite must be the case; pre-
mised, moreover, that the parts of the medium swing isochronous
with the aether, and not in conformity with its own elasticity.

XLIX. On the Oblique Aberration of Lenses.
By JOHN BRIDGE, M.A. University College, London*.

THE importance of destroying oblique aberration in the con-
struction of photographic lenses has induced me to attempt
the problem. This I have done in the manner which seemed
most suited to the purpose, which was to ascertain the point
where a given ray of a pencil emerging from any point of a flat

* Communicated by the Author.