The Absorption, Dispersion, and Surface-Colour of Selenium

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1902 Proc. Phys. Soc. London 18 148

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points as suggested by Prof. Everett. It was also pointed out that the criterion for anchor-ring or toric waves is that the focal lines are respectively a circle and a straight line perpendicular to the plane of the circle and lying in its axis, and that a toric wave-front could be formed by the refraction of a hollow cone of light at an annular ring on a spherical surface. The wave-front in the refracting medium is then toric, that is, it is a circular trough which is part of an anchor-ring. The primary focal line is a circle, and the secondary a straight line of limited length.

Prof. S. P. THOMPSON said that optical writers often used the term focal lines to denote the sections of the wave-surface made by two mutually perpendicular planes through the focal points.

XII. *The Absorption, Dispersion, and Surface-Colour of Selenium.* By R. W. WOOD, *Professor of Experimental Physics in the Johns Hopkins University**.

THE dispersion curves of substances with absorption-bands lying wholly within the visible or infra-red spectrum have been carefully examined within the past few years, in connexion with the modern theory of dispersion. To the best of my knowledge little or nothing has been done with substances in which the absorption begins in the visible spectrum and extends into the remote ultra-violet. Of these media amorphous selenium is a type, strong absorption beginning not far from the D lines, and increasing continuously with decreasing wave-length until, in the ultra-violet, the extinction coefficient has as high a value as in the case of metals. Another substance which I have found worthy of investigation is nitroso-dimethyl-aniline. This substance is most remarkable in its behaviour. It crystallizes in green laminæ which melt at 85 degrees and can be formed into fluid prisms between glass plates. These prisms must be kept fluid by an air-bath, as on solidification they become

* Read February 28, 1902.

opaque. A prism of four or five degrees gives a most astonishing dispersion when an incandescent lamp is viewed through it. It is quite transparent up to the greenish-blue, and gives a spectrum *twelve times as long as a quartz prism of equal angle*. Pressed into a thin film, it seems to be nearly as transparent as glass of a very pale canary-yellow colour; but if the transmitted light be examined with a spectroscope, the blue and violet end of the spectrum is cut off almost as sharply as if by an opaque screen in the eyepiece. This indicates an exceedingly steep extinction curve; and the course of the dispersion curve within this region will prove most interesting. I am at the present time engaged on the investigation of the absorption and dispersion of this substance, and further discussion will be postponed for the present.

Selenium I have already investigated with the assistance of Mr. A. H. Pfund, one of my students at the University of Wisconsin, to whom I am indebted for a large amount of very faithful work.

The only determinations that I have been able to find of the dispersion of this substance were made by Sirks* by the method of the colours of thin plates; a method involving considerable error, as is apparent from a comparison of his curve with the curve obtained by direct spectrometer measurements with selenium prisms.

These prisms were made in the same manner as the cyanine prisms which I have previously described (Proc. Phys. Soc. vol. xvii. p. 671). The substance is much more transparent than cyanine, and larger angles can consequently be used. Four or five degrees is about the maximum angle which can be employed to advantage. A strip of thin German plate-glass about 1 cm. wide and 2 cm. long is about right. A narrow strip of cardboard 1.5 mm. thick is pasted along the narrow edge, and a small piece of selenium fused on the opposite edge by holding the plate over a small flame. The other plate must be heated at the same time to about the same temperature, and the two clamped in a small vice in the manner described for cyanine prisms. It is necessary to

* Sirks, Dispersion des Selens, Pogg. Ann. cxliii. p. 429.

heat the plate until the substance is quite fluid, which is considerably above the temperature at which it becomes pasty. After the medium has solidified, one of the plates can be removed by a blow from a small hammer, if the prism is required for measurements with the spectrometer, as the angle can then be easily determined by the reflexion of light from the oblique surfaces. If the prism is to be used for demonstration only, it is better to leave the plate on. One of the prisms crossed with a diffraction-grating shows the dispersion curve very well when an arc-light is viewed through the combination.

Determinations were made of the dispersion by means of three selected prisms, the results of which are shown below.

The results obtained by Sirks are plotted for comparison. The values obtained with the different prisms agree very well except at the edge of the absorption-band, where the chance of error is much greater owing to the broadening of the image of the spectrometer-slit by diffraction, the light only passing through a very narrow strip of the prism bordering the refracting edge.

The spectrometer was illuminated with monochromatic light obtained by prismatic analysis, the wave-length being determined for each observation with a glass grating of 14,000 lines. I found it quite impossible to construct prisms of small enough angle to make determinations below wave-length 61

possible. With one very acute prism I fancied that I detected evidences of a decrease of refractive index after passing this point, and accordingly determined to follow the curve further down into the spectrum by means of the interferometer, in the same manner as has already been done in the case of cyanine.

Beautifully uniform films of selenium were obtained on plates of plane parallel glass, by means of a flat selenium cathode in a high vacuum. This cathode was made by rubbing a stick of selenium over a hot aluminium plate, the device being that used by Longden in obtaining films showing Newton's rings.

Displacements of the interferometer fringes by the films were obtained in the manner described in previous papers on the dispersion of cyanine and carbon; a film covering one half of each of the two interferometer paths giving double the displacement of a single film without any increased loss of light. The displaced fringes were photographed by monochromatic light of known wave-length, the photographs being subsequently measured with a filar micrometer.

In the photographic work some trouble was had with superfluous light which, being superposed on the image of the fringe system, lessened the contrast between the maxima and minima. Some of this light comes from the glass surfaces and some from the selenium films. Mr. Pfund finally got rid of this light by the ingenious device of placing a convex lens between the interferometer and the photographic plate, which brought the light to two point-foci less than a millimetre apart. A screen with a pin-hole held back the superfluous light, which was collected at one focus, allowing the light which formed the fringes to pass. It was also found that better results were obtained with unsilvered interferometer-plates.

When working in the red and orange comparatively thick films could be used, but in the blue and violet only exceedingly thin ones allowed any light to pass through.

The apparatus as arranged for photographing the fringes and measuring the wave-length of the monochromatic light employed, is shown in fig. 2. The light of an arc-lamp A falls on a mirror cemented to the back of a prism which stands on a

revolving graduated circle. The collimator objective T projects a spectrum on the slit S, which can be shifted by turning the circle which carries the prism. The monochromatic light which leaves the slit, after passage through a collimating-lens

FIG. 2.

I_1 , falls on the interferometer. Plane parallel plates carrying the selenium films are shown at b . To get rid of the multiple images, the lens M is arranged so as to focus the light on the perforated screen U *.

* By an error of the engraver the aperture in U is shown much too large. Only one of the two convergent beams passes through it.

No other lens is used, the light falling directly on the photographic plate after passage through the pin-hole.

The camera is simply a long narrow box, the plate being carried on a slide, so that eight exposures can be made one after the other on a single plate, measuring 12×2 cms.

A small mirror N, hinged in front of the slit, enables us to divert the light from the interferometer and throw it into the grating spectrometer S, by means of which the wave-length can be at once determined. By means of this arrangement it was possible to work with considerable rapidity. After each exposure, the small mirror was turned in front of the slit, and the cross-hairs of the spectrometer set on the diffracted image. The prism was then turned through a small angle and a second exposure given, the circle of the spectrometer being read while the exposure was in progress. The longest exposures in the red were only five or six minutes in duration.

After making a number of measurements in different parts of the spectrum by means of films of different thicknesses, it occurred to me that if a wedge-shaped film were employed, curved fringes would be obtained which would allow the displacement for any wave-length to be measured for the maximum thickness capable of transmitting the light. Films of this nature were obtained by shielding the plate during the deposition with a strip of mica mounted a centimetre or so above its surface, as shown in fig. 1. The drift of the

Fig. 3.

selenium under this shield was very regular, and excellent wedges were obtained which showed straight interference-bands when viewed in reflected light. A series of photographs obtained with one of these prismatic deposits is reproduced in fig. 3. It will be seen from the nature of the displacement of the fringes that the film is of nearly uniform thickness

for a short distance, and then becomes wedge-shaped, the fringes plunging down suddenly.

Another advantage of the wedge-shaped films is that the displaced fringe can be identified with the undisplaced. In working with films in the red and orange, where the displacement is equal to the width of several fringes, the only method of identifying the fringes is to make visual observations with white light at the centre of the system. With the wedge-shaped film there is no difficulty in telling which fringes belong together, for the same fringe can be traced clear across the plate, and the total displacement determined. The chance of making an error of an entire fringe-width in estimating the displacement by visual observations with white light is very great, owing to the great dissimilarity in the appearance of the chromatic fringes seen through clear glass and selenium.

The photographs of the curved fringes were measured by placing them in contact with a glass plate ruled with parallel diamond scratches, one of the scratches being placed in coincidence with the line marking the thin edge of the film. The displacement was measured as before with a filar micrometer, setting the cross-hair first on the undisplaced fringe, and then on the point at which the corresponding fringe intersected the scratch nearest the end of the oblique system.

The values for the refractive indices obtained in the red by means of the prisms were taken as a basis for the calculation of the indices in the rest of the spectrum from the interferometer measurements. If we find the displacement for wave-length λ_r to be n_r (n being measured in terms of fringe-width), and know the ref. index μ_r for this wave-length, we can determine the refractive index μ_g for wave-length λ_g (in the green) by measuring the displacement n_g for the same thickness, from the formula

$$\mu_g = 1 + (\mu_r - 1) \frac{n_g \lambda_g}{n_r \lambda_r}.$$

Determinations were made in this way down to wave-length $\cdot 0004$, beyond which point it was impossible to go owing to the powerful absorption, which made the fringes too faint to measure. It was only by employing exceedingly thin films

and making the measurements with the greatest care that consistent results were obtained in the violet. The reason for this will be apparent when the subject of absorption is taken up, for a film which in red light is so transparent that its presence cannot be detected, in the violet and ultra-violet absorbs nearly as strongly as a metal film of the same thickness.

The dispersion-curve obtained by means of the interferometer is given on fig. 4, points determined with uniform films being indicated by circles, while points determined with wedge-shaped films are denoted by crosses. The turning point of the curve is at wave-length $\cdot 0005$, where the refractive index reaches the value $3\cdot 13$, which, so far as I know, is the highest value ever found for any substance.

Fig. 4.

The continued rise of the dispersion-curve after entrance into the region of the absorption-band is worthy of notice, for usually the curve falls abruptly as soon as the band is entered. As the matter is of considerable theoretical importance it seemed best to check, if possible, the data furnished by the interferometer by means of very acute prisms. Examination of the wedge-shaped plate by means of sodium light, showed that a strip about 8 mm. wide was suitable for the purpose, the interference-fringes being straight, parallel, and equidistant. The angle was found from the fringes to be very nearly 22 seconds.

The deviations were observed by means of a large spectrometer, which I have recently set up for quantitative measurements of the dispersion of sodium vapour. The slit is illuminated by means of the monochromatic illuminator made by Fuess. The telescope has a focal length of 1.5 metres, the eyepiece being furnished with a filar micrometer. The graduated screw of the monochromatic illuminator, by means of which the wave-length of the light on the slit is changed, is operated from the eye-end of the telescope by means of a long steel rod, while the graduations are read by means of the finder of the telescope, which points towards a mirror in which a portion of the illuminator is seen reflected.

This arrangement is extremely convenient, for the observer can run rapidly through a series of observations without leaving his seat at the eyepiece, a matter of great importance when working with sodium prisms. The plane parallel glass plate with the selenium wedge was covered by a piece of black paper furnished with two apertures, one exposing the prism, the other a portion of the clear glass. The illuminator was set for red light, and the prism placed in front of the telescope: a small screen enabled either aperture to be covered. The image of the slit was slightly broadened by diffraction, but not enough to interfere with accurate setting of the cross-hairs. On changing from clear glass to the selenium wedge, a displacement equal to three times the width of the band was observed. If both apertures were opened simultaneously, both the direct and displaced images appeared in the field, the images being furrowed, however, by the fine interference minima due to two apertures. Though it is quite possible that these minima would furnish the means of a more accurate setting of the cross-hairs on the centre of the band, they were not made use of in the present case, the apertures being uncovered in succession. This seemed advisable in view of the uncertainty regarding the effect of the change of wave-length on their location, for it must be remembered that when working with the strongly absorbed blue light, the amplitude falls off rapidly across the selenium-covered aperture, its effective width contracting with decrease of wave-length. The angular deviation for the

red was measured, and found to agree fairly well with the observations made with prisms of larger angle. The selenium aperture being exposed, the cross-hair was set on the displaced image and the wave-length decreased. The image immediately moved off the hair, which was made to follow it, and a continued increase in the deviation was noted as far down the spectrum as wave-length $\cdot 00055$, beyond which point the image became too faint to observe.

I was disappointed not to be able to follow the curve to its turning point in the blue, and accordingly tried another method.

The wedge-shaped film was observed by the light of lithium, sodium, and thallium flames in succession, and the positions of the dark bands recorded by needle scratches. The eighth band for lithium light coincided with the tenth band for sodium light, which agrees well with the observed values of the refractive index. With thallium light only three bands next to the thin edge could be seen, owing to the strong absorption, but their position indicated an increase of refractive index, the third thallium dark band coinciding with the second lithium band. The first dark band moved nearer to the thin edge with decreasing wave-length. A screen consisting of a glass cell filled with a solution of cuprammonium and a sheet of dense cobalt glass was now placed in front of a Welsbach light. This gave a deep blue light free from red. In this case the first dark band was the only one that appeared, but it was distinctly nearer the edge than in the case of the thallium light, which shows that the wave-length of the blue light in the selenium is considerably less than the wave-length of the thallium light, which would not be the case if the refractive index for the blue was considerably less than for the green. In this last case the band was too ill-defined to admit of an accurate measurement of its position.

A preliminary examination of the light transmitted by a very thin film squeezed out between two plates of quartz, by means of a quartz spectrograph, showed that there was no return of transparency in the ultra-violet, at least up to wave-length $\cdot 00028$ or thereabouts. To determine if possible the position of the centre of the band, which gives us λ_m in the dispersion formula, a series of photometric measurements

were made of the visible and ultra-violet light transmitted by a thin film deposited *in vacuo* by means of the cathode discharge. In the visible spectrum measurements were made by placing the glass plate, partly covered by the film, in contact with the double slit of a spectrometer, the line terminating the film being brought into coincidence with the junction of the slits. The thickness of the film was determined by means of fringe displacements, making use of the data obtained with the selenium prisms.

Owing to the difficulty of obtaining accurate data in the blue and violet by the visual method, and to enable us to carry on a study of the absorption in the ultra-violet, a photographic method was adopted, the details of which were worked out largely by Mr. Pfund.

The double slit was removed and a single slit put in its place, which was opened to a width of 0.5 mm. The ocular slit of the spectrophotometer was also opened to the same width. A short distance behind the ocular slit, the photographic plate was mounted with the selenium film covering the upper portion. A part of the plate was therefore exposed to light coming through clear glass, and part to light which had passed through the film of selenium. This method was found to give better results than a previous method which we tried, which consisted in substituting a photographic plate for the eyepiece of the instrument, and using the Vierordt slit as in the visual method. To determine the ratio of the intensities we made use of a photographic wedge, made by giving to a long narrow photographic plate an exposure decreasing uniformly in duration. To this strip a graduated scale was attached, and it was arranged to slide in a frame behind a narrow vertical aperture, against which the plate which had been exposed in the instrument, developed and dried, could be placed immediately below the wedge, which was then moved along until the spot of equal density was found. This spot could be determined to within 1 mm., the total length of the wedge being about 10 cms. In this way very good ideas of the relative intensities could be obtained, assuming Roscoe's rule governing the blackening of a plate to be true, as it probably is within the limits comprised in our experiments.

Below is given a table showing the values of $\frac{I}{I'}$, the ratio of the intensities, obtained by the two methods for a film the thickness of which was 0.0001 mm., and the calculated values of the extinction coefficient κ , defined by the equation

$$\frac{I}{I'} = e^{-\frac{4\pi\kappa d}{\lambda}},$$

where d is the thickness of the film and e the base of the natural logarithms.

	$\frac{I}{I'}$ (Visual).	$\frac{I}{I'}$ (Photographic).	κ .
760	1.05	1.04	.0234
710	1.10	1.07	.0456
640	1.20	1.18	.0879
589	1.40	1.39	.155
550	1.80	1.80	.254
515	2.40	2.43	.358
490	3.40	3.44	.478
466	4.40	4.40	.571
442	6.20	6.15	.793
425	7.50	7.53	.677
415	9.50	9.46	.736
400	9.50	12.00	.785

The values of κ plotted as ordinates with wave-lengths as abscissæ give the extinction curve, which is reproduced on fig. 4 with the dispersion curve (p. 155).

To carry the work into the ultra-violet we abandoned the spectrophotometer with its glass prism and lenses, and made use of a short-focus concave grating with 14,000 lines to the inch. This grating was sent to me by Mr. Thorp of Manchester. It was made by mounting one of his celluloid replicas of a Rowland grating on a concave lens, the celluloid film being subsequently silvered. It was only intended as a device for illustrating the action of the concave grating*,

* I have mounted this grating on a light wooden frame designed according to the well-known Rowland device, which can be placed on the lecture-table and used for class illustration. The slit is illuminated with sun or arc light and the spectra received on a strip of ground glass. It is useful for showing how the spectra and the camera move relatively to each other.

but I found that if its aperture were reduced somewhat it gave surprisingly sharp lines.

A film of selenium was deposited on a thin plate of quartz, and mounted in front of the slit of the grating outfit, the lower half of the slit being covered with clear quartz, the upper half with quartz and selenium.

The slit was illuminated by a spark-discharge between zinc terminals, and the spectrum photographed. The absorbing action of the selenium manifested itself as a more or less complete obscuration of the upper half of the spectrum. By giving the selenium-covered portion of the slit a very long exposure, and the clear portion a short one, any given part of the spectrum could be balanced, the ratio of the times giving us an approximate value of $\frac{I}{I'}$.

We exposed a number of plates, and fully established the fact that the turning-point of the extinction curve, if it exists at all, lies beyond wave-length $\cdot 00022$. In the case of one plate the clear portion of the slit was exposed for 30 seconds, the selenium-covered portion for 62 minutes. The resulting photograph showed lines down to wave-length $\cdot 00022$ for the clear part of the slit, while the selenium-covered part only recorded itself down to $\cdot 00028$, the lines being, however, very much fainter than the corresponding ones in the other half of the spectrum. The lines were of about the same intensity at wave-length $\cdot 00033$, for which we get, from the ratio of the times of exposure, the value $1/124$ for I/I' . This gives us the value $1\cdot 255$ for κ . The thickness of the film was the same as in the previous experiments. Still longer exposures would have to be given to balance the two halves of the spectrum for shorter waves than these, from which it is evident that the extinction curve is still rising rapidly at wave-length $0\cdot 00022$, where the coefficient has as high a value as in the case of the metals.

The extinction curve as figured is not to be regarded as very accurate, as no precautions were taken to eliminate the reduction in the intensity of the light due to the reflexion at the surface. In determining curves of absorption it is always better to use two films of different thickness. The errors in

the case of selenium may be considerable on account of the high refractive index, and I expect to redetermine the curve in the near future. In the present preliminary work the object was merely to determine whether there was a return to partial transparency in the ultra-violet region, which question appears to be answered in the negative, although a possible turning-point in the curve may be masked by the high reflexion coefficient. It appears to me to be extremely doubtful that there is but a single absorption-band in the present case, the more probable condition being a series of overlapping bands. We are in fact forced to this conclusion if we attempt to apply the dispersion formula to the results. Though we are unable to determine experimentally the value of λ_m , the wave-length corresponding to that at the centre of the absorption-band, we can calculate a value for it from three determinations of the refractive index in the region of comparative transparency. Writing the dispersion formula in the form*

$$n^2 = m + \frac{m'\lambda^2}{\lambda^2 - \lambda_m^2}$$

we can calculate λ_m from

$$\lambda_m^2 = \frac{\lambda_3^2(\lambda_1^2 - \lambda_2^2) - \lambda_2^2(\lambda_1^2 - \lambda_3^2)C}{(\lambda_1^2 - \lambda_2^2) - (\lambda_1^2 - \lambda_3^2)C},$$

in which

$$C = \frac{n_2^2 - n_1^2}{n_3^2 - n_1^2},$$

where n_1 , n_2 , and n_3 are the values of the refractive index for wave-lengths λ_1 , λ_2 , and λ_3 . Applying this formula to the values determined by the prism method we find λ_m to be 0.00056, which we may assume to be not very far from the centre of the first band in the series. The true position of the centre of the first member of the series cannot be exactly determined, owing to the effects of the free periods of higher frequency, but the value given above can be considered a fair

* "Dispersion of Ultra-Violet Rays," F. F. Martens, *Annalen der Physik*, No. 11, p. 612 (1901).

approximation. Ketteler has given a method for decomposing a complex absorption-band into its constituents; but as the process is very laborious and somewhat arbitrary, it has not seemed worth while to attempt to apply it until a more accurate curve has been determined.

If we take into account the first member of the series only, and apply the results obtained with the prisms to the formula

$$n^2 = b^2 + \frac{M_1}{\lambda^2 - \lambda_m^2},$$

from which the other formula may be derived by letting $b^2 = m + m'$ and $M_1 = m'\lambda_m^2$, in which b^2 is the dielectric constant, we find b^2 to be very nearly 6.0. This latter form of the formula is the one generally used. If we use the original formula and determine m' and m from the expressions

$$m' = \frac{(n_3^2 - n_1^2)(\lambda_1^2 - \lambda_m^2)(\lambda_3^2 - \lambda_m^2)}{\lambda_m^2(\lambda_1^2 - \lambda_3^2)},$$

$$m = n_2^2 - \frac{m'\lambda_2^2}{\lambda_2^2 - \lambda_m^2},$$

we find

$$m = 5 \text{ and } m' = 1.02$$

or

$$b^2 = m + m' = 6.02.$$

If m in the original formula turns out to be greater than unity, it indicates that other absorption-bands must be taken into account. The dielectric constant of selenium has been measured by Romich and Nowack, the value found being 10.2.

The dielectric constant of a substance according to the electromagnetic dispersion theory is the dielectric constant of the æther, plus the dielectric constants of the various ions whose action on the æther waves gives rise to the phenomena of absorption and dispersion. Until the behaviour of selenium in the infra-red region has been investigated, it will be impossible to say whether the high value of the dielectric constant is due wholly, or only in part, to the ions whose free periods correspond in frequency to the green, blue, and ultra-violet rays. The infra-red work is already

under way, and until it is completed further discussion of the results given in the present paper is impossible*.

The very high values of κ in the ultra-violet led me to look for traces of selective reflexion in this region. The light of an arc-lamp was reflected successively from six surfaces of selenium deposited on glass. The image of the crater after the sixth reflexion was very faint, but so far as the eye could judge without trace of colour. To determine whether or not ultra-violet light was present in excess, the light from the sixth surface was received upon a photographic plate one half of which was covered with a plate of glass which would absorb everything below wave-length $0\cdot00034$. The two halves of the plate were equally blackened, indicating that light of shorter wave-length than the above value was not present in any great excess.

Metals, however, have a much weaker reflecting power for ultra-violet radiations than for waves in the visible spectrum, and the failure to obtain traces of ultra-violet "Rest-strahlen" is doubtless due to related causes.

At the time when these experiments were tried the question of the possible detection of "Rest-strahlen" in the ultra-violet had never been discussed so far as I know. A paper has since appeared by Martens (*loc. cit.*) in which experiments are described which appear to prove that selective reflexion in the ultra-violet actually exists in certain circumstances.

We must be on our guard, however, against the error often made in assuming that the rays most strongly absorbed are identical with those most strongly reflected. This statement appears in so many of the text-books that it is well to call attention to the fallacy. Selective reflexion depends quite as much upon the refractive index of the medium as on the absorption. The index has a high value on the red side of the absorption-band, and a low value on the blue side; consequently the strongest reflexion will be for those rays on the red side of the centre of the absorption-band; that is to say

* Since writing this paper, I have had the opportunity of examining the infra-red transmission up to wave-length 23μ with Prof. Mendenhall's very sensitive bolometer at the University of Wisconsin. No absorption-bands were found up to this point.

the maximum of the reflexion curve is shifted in the direction of the longer wave-lengths with respect to the absorption curve. The minimum of the reflexion curve lies on the blue side of the absorption-band, and in some cases may be equal to zero. The whole thing is of course contained in the formula for reflexion from absorbing media, which states that the percentage reflected,

$$R = \frac{n^2(1 + \kappa^2) + 1 - 2n}{n^2(1 + \kappa^2) + 1 + 2n}.$$

I have calculated from Pfüger's values of n and κ the reflexion curve which represents the surface colour of cyanine at normal incidence (fig. 5), which illustrates well the fact

Fig. 5.—Curve illustrating Surface-colour of Cyanine.

that the intensity of the reflected light in different parts of the spectrum is in no way a measure of the absorption. In point of fact, it is easily seen that the characteristic plum-colour of cyanine films is due rather to the almost complete *absence* of reflexion of the green rays than to strong metallic reflexion of any particular colour.

In the case of selenium, if we apply the reflexion formula to the data that have been obtained thus far, we obtain a curve which indicates that the reflexion increases rapidly with decreasing wave-length. As I have said before, multiple reflexions from selenium surfaces give no trace of colour,

which suggests that errors may exist in either the refraction or extinction curve. I have already pointed out where the source of trouble may lie in the case of the latter curve. In regard to the refraction-curve, it may be considered fairly accurate up to the point where the prism determinations stopped. In the case of films the thickness of which is less than the wave-length of light, I do not yet feel sure that the displacement of interference-fringes gives us a true measure of the refractive index. I hope some time to make a rigorous test of this point, for so far as I know it has never been settled.

The fact that the dispersion-curve of cyanine determined by the interferometer agreed so well with the curve obtained by means of a thin prism, does not prove conclusively that the method is not open to objection; for the same errors might occur in both cases: in other words, the deviation produced by a prism, the base of which was only a wave-length or two thick, might be affected by phase changes at the surfaces.

Selenium shows a strong surface-colour if the angle of incidence is in the neighbourhood of the polarizing angle, and the reflected light is examined through a nicol turned so as to extinguish as much as possible of the reflected light. The colour ranges from a greenish white through blue to deep violet as the angle of incidence increases.

The elliptical polarization of light reflected from selenium and the determination of the absorption and dispersion curves by the katoptric method is now in progress, as well as an investigation of the behaviour of the substance in the infra-red. It will be interesting to compare the results obtained in this way with the results obtained by the dioptric method.

The refraction and extinction curves for selenium, obtained by the katoptric method, are given in Ketteler's 'Theoretical Optics,' p. 552; but it is not stated whether the experiments were made with the glassy or metallic modification. The refraction curve in the red and orange region is obviously wrong, if it is intended to represent the dispersion of the glassy modification, as can be seen by comparing it with the curve obtained with the prisms.

DISCUSSION.

Prof. S. P. THOMPSON exhibited some tellurium mirrors made in the same way as the selenium ones used by Prof. Wood.

XIII. *A suspected case of the Electrical Resonance of Minute Metal Particles for Light-waves. A New Type of Absorption. By R. W. WOOD, Professor of Experimental Physics in the Johns Hopkins University*.*

CERTAIN experiments on which I have been engaged of late have led me to believe that I have found a new type of light absorption, which it may be possible to refer to the electrical resonance of small metallic particles for waves of light. The experiments of Garbasso and Aschkinass have shown that a plate of glass covered with uniformly arranged strips of tinfoil of equal size, which serve as resonators, shows the phenomenon of selective transmission and reflexion for electromagnetic waves of different wave-lengths. In other words, a plate of this description exhibits the electrical analogy of surface-colour. I have succeeded in producing metallic deposits on glass which the microscope shows to be made up of particles smaller than the wave-lengths of light, which by transmitted light exhibit colours quite as brilliant as those produced by aniline dyes. I have sought in every way to explain these colours, by all the well-known principles of interference and diffraction, and at the present am forced to accept the hypothesis suggested in the title of this paper, which I have chosen not without some misgivings.

In the present paper I shall content myself with giving a full account of the experimental data which I have thus far obtained, postponing for the present anything like a definite conclusion.

The metallic deposits are obtained by heating small fragments of the alkali metals in glass bulbs, thoroughly exhausted and hermetically sealed. Only the small portion of the bulb on which the metal particle lies is heated, leaving the

* Read March 14, 1902.