XXXVI. The anomalous dispersion of carbon

Prof. R. W. Wood

To cite this article: Prof. R. W. Wood (1901) XXXVI. The anomalous dispersion of carbon , Philosophical Magazine Series 6, 1:4, 405-410, DOI: [10.1080/14786440109462627](https://doi.org/10.1080/14786440109462627)

To link to this article: <http://dx.doi.org/10.1080/14786440109462627>

Published online: 08 Jun 2010.

Submit your article to this journal [↗](#)

Article views: 4

View related articles [↗](#)

measure one of the vapour-pressures than the other. Suppose p_1 to be measured, then

$$\log p_2 = - \int \frac{x}{1-x} \frac{d \log p_1}{dx} dx.$$

Hence

$$\log p_2 = \left[\frac{-x}{1-x} \log p_1 \right] + \int \frac{\log p_1}{(1-x)^2} dx,$$

and the numerical solution becomes practicable.

XXXVI. *The Anomalous Dispersion of Carbon.*

*By Prof. R. W. WOOD *.*

IT was suggested to me some time ago by Professor Ames that the rapid decrease of amplitude on a wave-front, resulting from its passage through a prism of some strongly absorbing substance, such as cyanine, might not be without influence on the direction of propagation of the transmitted ray.

In Huygens's construction a constant amplitude is assumed over the wave-front, and it is quite conceivable that varying the amplitude might shift slightly the position of the "effective-point."

There are obviously two ways of attacking the problem: the mathematical and the experimental. I have been unable to treat the case by any of the geometrical methods, and the simplest way seems to be to determine the form and position of the intensity curve, treating the transmitting edge of the prism as a narrow aperture, the amplitude decreasing across its width according to some linear function, and solving by the method employed in the case of the Fraunhofer or telescopic diffraction phenomena. I have not yet attempted the solution in full, but a cursory examination leads me to anticipate that the central maximum will not be symmetrical with respect to the centre of the system. The highest point of the intensity curve will undoubtedly be at its usual place, in the line normal to the centre of the aperture, but the slope may be steeper on one side than on the other. In all determinations of the refractive index of strongly absorbing prisms, when working near the absorption-band, the slit image is broadened by diffraction. By setting the cross-hair of the eyepiece on the centre of this broadened image, we assume that we have determined the centre of the system. If, however, the central maximum of the pattern is unsym-

* Communicated by the Physical Society.

metrical, it is clear that a considerable error may be introduced in this way.

For a direct experimental test we require some means of cutting down the amplitude without introducing a retardation or change of phase. In searching for a possible substance which would absorb but not retard, I tried films of smoke on glass. It seemed possible that, since the absorption is caused by very minute opaque particles of carbon, the wave might be transmitted without retardation. If this were found to be the case a wedge-shaped film of smoke would furnish the necessary conditions. Examination of the films by means of the interferometer showed, however, that a very marked retardation was introduced. This phenomenon I subsequently found had been previously observed by Rosicky * and Stark †.

Stark's results indicated that in the case of films deposited by coal-gas flames, we are dealing with a porous mass consisting of 2.28 per cent. of pure carbon, and 97.72 per cent. of air. He considered the case as that of a turbid medium made up of air with a low, and carbon with a high refractive index, such mixtures being known to possess a refractive index intermediate between the indices of the constituent parts. He made no determinations of the dispersion.

It occurred to me that the retardation in this case might be ascribed to diffraction, there being an increase of path due to the passage of the light waves around the carbon particles, the case being analogous to the passage of a sound-wave through a medium containing obstacles symmetrically distributed. I succeeded in photographing the retardation of a sound-wave resulting from its passage through several layers of glass tubes, placed side by side with spaces between. If the retardation of the light by carbon films is due to diffraction, we should expect either to find dispersion absent, which would mean that the path increase is the same for all waves, or else a greater retardation for the long waves than for the short.

An attempt was at once made to determine the presence or absence of dispersion, the experiments showing conclusively that the long waves (red) were retarded more than the short ones (violet), the condition found *within* the absorption-band in the case of substances showing anomalous dispersion. Experiments were made with smoke-films, and with films deposited in a vacuum on plate-glass by the filament of an incandescent lamp. The average diameter of the carbon

* Rosicky, *Sitzb. Ber. Wien. Ak.* 1878.

† Stark, *Wied. Ann.* lxii. p. 351.

particles in smoke-films is less than 0.00026 mm., while the regular reflexion at normal incidence of violet light by the deposited films indicates that the diameter of the particles must be less than one-eighth of the wave-length of violet light. (Assuming $\frac{1}{4}\lambda$ to be the maximum allowable phase-discrepancy.)

The dispersion was first measured with a Michelson interferometer, illuminated with monochromatic light of various colours obtained by prismatic analysis. The fringes were photographed and measured as described in the paper on Cyanine*, readings being obtained between wave-lengths .00040 and .00066. The results showed a steady increase of refractive index in passing from blue to red. The results obtained with the deposited films were less satisfactory, owing to the poor quality of glass. They were prepared in the following way:—An incandescent lamp bulb was cut in two and a small piece of German plate-glass introduced; the two halves of the bulb were then sealed together in the blowpipe flame, and the air exhausted, after which the lamp was run for several hours at considerably above its rated candle-power. Very uniform metallic-like films were obtained in this way, which gave elliptic polarization. The poorness of the glass, however, made accurate measurements impossible, owing to the irregular curvature of the fringes, and the work will be repeated with films deposited on plane-parallel optical glass. This seems to be important, since it seems quite possible that the films may be molecular in structure; the particles are certainly much smaller than in the case of the smoke-films, and may give a different dispersion curve. As far as it was possible to judge the deposited films showed the same anomaly as the smoke-films.

No attempt was made to determine the absolute refractive index, since accurate determinations of the thickness of the smoke-films are difficult. Even were this possible the values obtained would not mean much. Relative values only were obtained, as indicated in the following table, where n represents the fringe displacement, *measured in fringe-widths*, λ the wave-length, and $n\lambda$ the product which is proportional to the refractive index, as shown by the usual formula

$$(\mu - 1)e = n\lambda,$$

where e is the thickness of the film.

* "The Anomalous Dispersion of Cyanine," R. W. Wood and C. E. Magnusson, *Phil Mag.* Aug. 1900.

n .	λ .	$n\lambda$.
·853	663	566
·923	605	558
·960	566	543
1·037	520	539
1·064	479	510
1·121	436	490
1·149	414	476

In the case of the films deposited by the lamp, which do not have the exceedingly porous structure of the smoke-films, we can easily determine the thickness by substituting the half-coated plate for the back mirror of the interferometer, and measuring the shift of the fringes at the edge of the reflecting carbon-film. A displacement of one third of a fringe was found with sodium light. The thickness was therefore $\frac{1}{3} \times \frac{1}{2} \times \cdot 000589$ or $\cdot 000098$ mm. The displacement of the sodium-light fringes corresponding to four transmissions (two films in optical juxtaposition being used as described in the paper on cyanine) was $0\cdot 784$ of a fringe, or $0\cdot 196$ for one transmission. We have then, substituting in the formula

$$(\mu - 1) \cdot 000098 = 0\cdot 196 \times \cdot 000589$$

$$\mu - 1 = 1\cdot 2,$$

or the refractive index $\mu = 2\cdot 2$, not very far from that of the diamond.

Fig. 1.

Formation of smoke-prisms.

One instinctively places more reliance on determinations of refractive index made by prismatic deviation than on those based on interference methods, and an attempt was accordingly made to verify the results with carbon prisms. By arranging a very small pointed gas-flame close to the edge of a glass plate, and sliding a piece of plane parallel optical glass back and forth against a guide (the tip of the flame just

touching it), very uniform prismatic deposits of smoke were secured. Viewed in reflected light the films showed Newton's interference colours, and the prisms were judged by observing whether the coloured bands were straight and properly spaced.

A suitable prism having been selected, the plate was covered with a piece of black paper perforated with two rectangular openings of equal width.

One of these openings, which was several times higher than the other, was over the prism, while the other covered clear glass close to the refracting edge of the prism. The object of using diaphragms of the same width but of different heights was to secure similarity of the deviated and undeviated images of the slit. The width of the central maximum depending on the width of the opening alone, the height could be increased to allow the passage of more light in the case of the dark prism.

The plate was then placed in a large direct-vision spectro-scope (from which the prisms had been removed) and the slit illuminated alternately with red and blue light. A very intense light being necessary the electric arc was used, the slit being covered alternately with deep ruby glass and a glass trough containing a strong solution of cuprammonium combined with a cyanine film. Prismatic analysis was found to weaken the light too much.

The diaphragms were covered alternately, and readings taken of the position of the slit image with a filar micrometer. The following readings were obtained:—

Red.	Blue.
Distance between dev. and undev. image in divisions of micrometer.	Distance between dev. and undev. image in divisions of micrometer.
55	40
60	50
59	41
58	48
57	45
58	46
53	43
56	39
55	44
61	40
<hr/>	<hr/>
57·2 mean.	43·6 mean.

In order to see how these readings agreed with the deviation calculated from an interferometer determination of the
Phil. Mag. S. 6. Vol. 1. No. 4. April 1901. 2 E

retardation at the base of the prism, the plate was set up in front of one of the mirrors of the instrument, a plate of equal thickness being introduced in the other optical path as a compensator. The fringes sloped abruptly down across the face of the prism, the displacement at the base being 1.7 of a fringe for the double transit of Na light, or .85 for a single passage. The retardation is therefore $.00059 \times .85$ or $.0005015$ mm. The width of the prism was 2.24 mm., therefore the angle through which the wave-front should be turned is given by

$$\tan \theta = \frac{.0005105}{2.24}$$

$$\theta = 46''.$$

The actual deviation as observed in the spectroscope was determined as follows:—

Calibration of the filar micrometer showed that one complete revolution of the head (100 divisions) corresponded to .248 mm.; 50 divisions, the mean between red and blue corresponding approximately to the deviation for sodium light, represents a shift of .124 mm.

The focal length of the telescope was 600 mm., and the deviation is given by

$$\tan \theta = \frac{.124}{600}$$

$$\theta = 43'',$$

which agrees very well with the calculated deviation of 46''.

While the results obtained are what we should expect if the diffraction theory were true, they do not of course prove it; and it will not be safe to draw deductions until more accurate results have been obtained with the metallic deposits obtained from the incandescent carbon filament. A method of compensation has been devised, which will make observations with much thicker films possible.

In conclusion I must thank Dr. C. E. Magnusson for much valuable assistance in photographing and measuring the fringes.

Physical Laboratory of the University of
Wisconsin, Madison.