



XXXIII. The achromatization of approximately monochromatic interference fringes by a highly dispersive medium, and the consequent increase in the allowable path-difference

R.W. Wood

To cite this article: R.W. Wood (1904) XXXIII. The achromatization of approximately monochromatic interference fringes by a highly dispersive medium, and the consequent increase in the allowable path-difference , Philosophical Magazine Series 6, 8:45, 324-331, DOI: [10.1080/14786440409463202](https://doi.org/10.1080/14786440409463202)

To link to this article: <http://dx.doi.org/10.1080/14786440409463202>



Published online: 15 Apr 2009.



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



View related articles [↗](#)



Citing articles: 2 View citing articles [↗](#)

of the D lines did not provoke the fluorescence. Wiedemann and Schmidt observed a bright band in the fluorescence spectrum in the case of vapour confined in glass bulbs which appeared to coincide with the D lines. The same appearance I afterwards observed independently, but on continuing the study of the subject was forced to refer the existence of this band in the yellow to sodium in the flame which heated the bulb. This I have since found was a mistake, for on repeating the experiments with exhausted glass bulbs, I have succeeded in stirring up a faint fluorescence with approximately monochromatic light from the illuminator already referred to, of wave-length equal to that of the D lines. The failure to observe it in the case of the experiments made last year by Mr. Moore and myself was due to the fact that this yellow light was removed from the incident beam by the sodium vapour before the light-rays met at the focus. This work is still in progress, and the fluorescent spectra given by the vapour when illuminated with monochromatic light of various wave-lengths have been photographed.

The investigations recorded in the present paper have been made possible by a very generous grant from the Rumford Fund, and I wish to express to the Trustees of the fund my appreciation of and thanks for the aid which I have received.

I wish also to express my appreciation of the very faithful work done by my assistant, Mr. A. H. Pfund, who has worked with me and made many valuable suggestions, and my thanks to the Board of Trustees of the Carnegie Institution for the means placed at my disposal by which I have been able to secure his services.

Johns Hopkins University, Baltimore, Md.,
May 28, 1904.

XXXIII. *The Achromatization of Approximately Monochromatic Interference Fringes by a Highly Dispersive Medium, and the consequent Increase in the Allowable Path-difference.*
By R. W. WOOD, Professor of Experimental Physics,
Johns Hopkins University*.

THE results recorded in the present paper were, for the most part, obtained during the progress of an investigation of the dispersion of sodium vapour. As I have mentioned in the previous paper, the path-difference under

* Communicated by the Author.

which it is possible to obtain interference-fringes with helium (D_3) light can be more than doubled by the introduction of a small amount of sodium vapour into the path of one of the interfering beams. This development of fringes far out in the system by the dispersive action of the vapour is accompanied by their complete disappearance at the centre of the system, where the difference of path is zero.

In order to understand this action of the vapour we must first consider briefly the conditions under which fringes may be visible.

Suppose that we have a system of circular fringes formed with white light, and consider a point just outside of the visible ring system, where the illumination appears uniform. Our fringe system is built up of an infinite number of coloured systems which are in coincidence at the centre, but which get more and more out of step as we advance out into the system, owing to the fact that the "scale" on which the Newton rings are formed decreases with decreasing wavelength. Let us now consider in what manner fringes may be made to appear at a point where the overlapping is so great as to destroy all trace of the fringes; in other words, how may achromatization be more or less completely secured.

It appears to me that there are only two conceivable ways in which the result can be obtained. If we could, by the introduction of a dispersing medium, increase the diameters of the blue rings without greatly affecting the diameters of the red ones, it is obvious that we should greatly increase the number of visible fringes without, however, altering their distinctness at the centre of the system.

A slight inclination of either of the back mirrors of the interferometer increases or diminishes the scale on which the fringes are formed, and since a similar change in the direction of the reflected rays can be effected by the introduction of an acute prism, it is easy to see that, owing to the dispersion of the latter, the change in the scale will be different for the different wave-lengths, more or less perfect achromatization resulting.

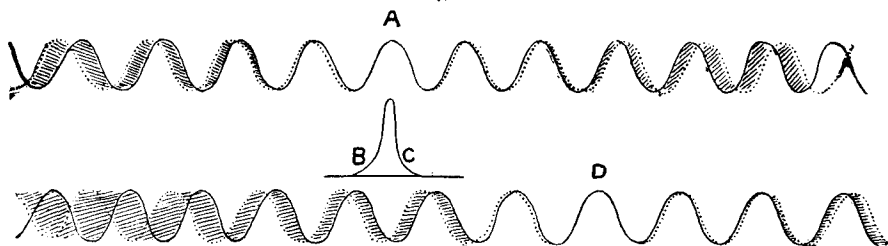
The introduction of a medium into the path of one of the interfering beams causes a shift of the fringe system as a whole, and if the medium is dispersing the shifts will be different for the different colours. The red, green, and blue fringes, which are out of step at a given point, may thus be brought into coincidence by the inequality of their respective displacements. In this case, however, since the systems are shifted as a whole, the fringes will be thrown out-of-step at the centre of the system, consequently we have obtained an

increase in the distinctness far out in the system, at the expense of distinctness at the centre. This is precisely what happens in the case which we are considering.

It has been found in every case that the introduction of sodium vapour into one path of the interferometer increases the distinctness of the fringes in a portion of the system which is brought into the field of the instrument by increasing the length of the other path.

We will now consider the case of the helium fringes, which under ordinary circumstances disappear when the path difference is between 1.5 and 2 cms., there being no recurrence of visibility by further increment of path difference as in the case of sodium light. We must therefore regard the helium (D_3) line as a single line of finite breadth or a close group of lines. In fig. 1 let BC represent

Fig. 1.



the intensity curve of the helium light, C being the edge of shorter wave-length. Immediately above we have a schematic representation of the fringe system, with its centre at A. Light from the side B of the D_3 line will produce the fringes indicated by the dotted line, which are farther apart than the fringes formed by the light of shorter wave-length coming from the side C of the line. There will, in addition, be an infinite number of other systems formed by light of wave-lengths intermediate between B and C which I have indicated by light shading.

Now suppose sodium vapour to be introduced into one path of the instrument, and the whole system shifted slightly to the left in consequence. Owing to the enormous dispersive power of the vapour, the dotted system (longer λ 's) will be shifted more than the other, since the D_3 line lies on the blue side of the sodium absorption-band, and the change in the velocity of the light is greatest for the longest waves, namely, those on the B side of the line. The result of this dispersive action is that the fringes are brought into step at a point D, to the right of the centre, thrown out-of-step at

the centre, and still more out-of-step to the left of the centre. If we had but the two systems indicated by the solid and dotted lines, it is obvious that the systems would come into-step again to the left of the centre, a condition which would occur if D_3 consisted of two infinitely narrow lines very close together. In the actual case the presence of waves of length intermediate between those of B and C make such a recurrence of visibility to the left of the centre impossible, and we have distinct fringes to one side only of the original centre of the system. On increasing the density of the sodium vapour, the point D of maximum visibility moves further along to the right, and to keep the fringes in the field it is necessary to turn the screw of the instrument in such a direction as to cause the system to move in *the same direction as the shift* due to the sodium vapour.

Now the sodium vapour accelerates the helium light, since its refractive index is less than unity for light of shorter wave-length than that of D_2 , consequently the reduced path is less. To shift the fringes in the same direction as that resulting from the shortening of the path through the sodium vapour, we must *lengthen* the other or air-path, which is precisely what was found to be the case as I have already said.

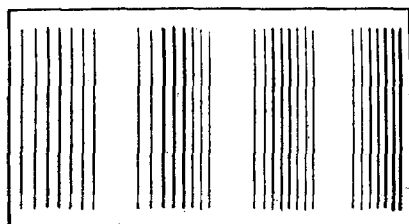
If the D_3 line lay on the other side of the D lines, the shift would be in the opposite direction, *i. e.* to the right, and we might at first sight expect the point of maximum visibility to shift to the left of the centre. We must, however, remember that in this case the change of velocity is greatest for the *shortest* waves on the side C of the line; consequently the system indicated by the solid line will suffer the greatest displacement, and we shall have coincidence at D, to the right of the centre, exactly as before. To test this point experimentally, the interferometer was illuminated with light from the monochromatic illuminator, a narrow band on the green side of the D lines being utilized. The formation of sodium vapour in one of the paths gave rise to the same changes as were produced in the case of the helium light, it being necessary to increase the air-path to prevent the fringes from disappearing. If the fringes were made very narrow, so as to occupy only a small portion of the field, the wandering of the system to one side could be easily watched, as the sodium vapour was formed. It must be understood that only a very small *displacement* occurs, the wandering of the system being merely a change in position of the region over which fringes can be seen. On repeating the experiment with a band of approximately monochromatic light on

the red side of the D lines, a similar drift of the position of maximum visibility was observed, and the direction of the drift was the same as before. In the case of helium light I have been able to increase the path difference to five or six centimetres, or to nearly treble it.

The achromatizing action of the sodium vapour is most beautifully shown if we illuminate the interferometer with white light.

Under ordinary conditions only two or three black and white fringes are seen, bordered on each side by perhaps a dozen rainbow-coloured bands, which fade rapidly into a uniform illumination. If sodium vapour is formed in one of the interferometer paths, the coloured fringes rapidly achromatize, and increase in number, breaking up, however, into groups as shown in fig. 2. As the density of the vapour

Fig. 2.



increases the number of groups increases, each group, however, containing fewer fringes. The position of the centre of the grouped system drifts in the same direction as the point of maximum visibility in the previous experiments.

The explanation of the altered appearance of the fringes in this case is not as simple as in those previously considered. We are dealing with two wide ranges of wave-lengths on opposite sides of the absorption-band. The fringe shifts of the two spectral regions will be in opposite directions, while the drifts of the points of maximum visibility will be in the same direction. It appeared as if this might increase the width of the region over which fringes could be observed, for the red-orange fringes are shifted in one direction and the yellow-green in the opposite. Each set would be more or less perfectly achromatized, and in the region in which they overlapped we should expect a periodic visibility, owing to the difference in the widths of the fringes of the two systems.

To test the point it seemed best to work with a narrow

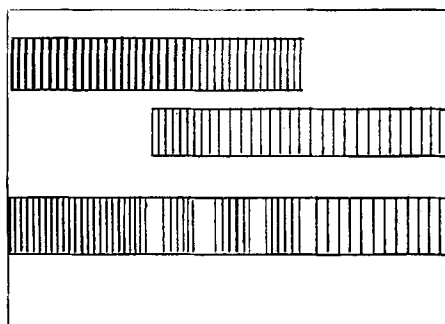
range of the spectrum symmetrical about the D lines. This was obtained by opening the slit of the monochromatic illuminator, bisecting it with a wire, and adjusting the prisms so that the region of the D lines was screened off by the wire. By means of a small screen either of the two narrow portions of the spectrum bordering the D lines could be screened off.

The effect of the sodium vapour on the fringes formed when the interferometer was illuminated by either one or both of the two portions of the spectrum could then be studied at leisure.

It was found that when a considerable amount of the vapour was present the apparent centre of the greenish-yellow fringe system was widely separated from the centre of the orange-yellow system.

When both sorts of light were used at once there was a periodic visibility in the region in which the two systems overlapped, the appearance in the three cases being shown in fig. 3.

Fig. 3.



The case is a little more complicated when white light, or the entire spectrum, is used, but it does not differ materially from the special case just considered.

Practically the same thing occurs when the interferometer is illuminated with sodium light, except that in this case the density of the sodium vapour in the optical path must be very much smaller. A periodic visibility results even when the light of one of the D lines is removed by the polarizing system described in the previous paper. The case is of course similar to the last-mentioned, for the width of the D line illuminating the instrument is greater than the width of the absorption-band of the rare vapour. We thus have a condition identical with that which we had when

the emitting slit of the monochromatic illuminator was bisected with a wire which cut out the D lines from the narrow band of the spectrum which was utilized.

Note by Lord RAYLEIGH.

Having had an opportunity of seeing the above paper in proof, I append with Prof. Wood's permission a few remarks.

The remarkable shift of the bands of helium light when a layer of sodium vapour is interposed in the path of one of the interfering pencils, is of the same nature as the displacement of the white centre found by Airy and Stokes to follow the insertion of a thin plate of glass. If D denote the thickness of the plate and μ its refractive index, $(\mu-1)D$ is the retardation due to the insertion of the plate, and if R be the relative retardation due to other causes, the whole relative retardation is

$$R + (\mu-1)D, \quad \dots \dots \dots (1)$$

in which R and D are supposed to be independent of the wave-length λ , while μ does depend upon it. The order of the band (n) is given by

$$n = \frac{R + (\mu-1)D}{\lambda} \dots \dots \dots (2)$$

For the achromatic band in the case of white light, or for the place of greatest distinctness when the bands are formed with light approximately homogeneous, n must be stationary as λ varies, *i. e.*,

$$\frac{dn}{d\lambda} = 0. \quad \dots \dots \dots (3)$$

For a small range of wave-length we may write

$$\lambda = \lambda_0 + \delta\lambda,$$

so that

$$\begin{aligned} n &= \frac{R + \left(\mu_0 + \frac{d\mu}{d\lambda_0}\delta\lambda - 1\right)D}{\lambda_0 + \delta\lambda} \\ &= \frac{R + (\mu_0-1)D}{\lambda_0} + \frac{\delta\lambda}{\lambda_0} \left(D \frac{d\mu}{d\lambda_0} - \frac{R + (\mu_0-1)D}{\lambda_0} \right) \dots (4) \end{aligned}$$

The achromatic band occurs, not when the whole relative retardation (1) vanishes, but when

$$R + (\mu_0-1)D = D\lambda_0 \frac{d\mu}{d\lambda_0} \dots \dots \dots (5)$$

If D be great enough, there is no limit to the shift that may be caused by the introduction of the dispersive plate.

As Schuster has especially emphasized, the question here is really one of the *group-velocity*. Approximately homogeneous light consists of a train of waves in which the amplitude and wave-length slowly vary. A *local* peculiarity of amplitude or wave-length travels in a dispersive medium with the *group* and not with the *wave-velocity*; and the relative retardation with which we are concerned is the relative retardation of the groups. From this point of view it is obvious that, what is to be made to vanish is not (1) in which μ is the ratio of wave-velocities V_0/V , but that derived from it by replacing μ by U_0/U , or by V_0/U , where U is the group-velocity in the dispersive medium. In vacuum the distinction between U_0 and V_0 disappears, but in the dispersive medium

$$U = \frac{d(kV)}{dk}, \quad \dots \dots \dots (6)*$$

k being the reciprocal of the wave-length in the *medium*. If we denote as usual the wave-length *in vacuo* by λ ,

$$k = \frac{2\pi\mu}{\lambda} = \frac{2\pi V_0}{\lambda V}. \quad \dots \dots \dots (7)$$

Accordingly

$$\frac{V_0}{U} = \frac{V_0 dk}{d(kV)} = \frac{d(\mu/\lambda)}{d(1/\lambda)} = \mu - \lambda \frac{d\mu}{d\lambda}. \quad \dots \dots \dots (8)$$

Substituting this for μ in (1), we see that the position of the most distinct band is given by

$$R + \left(\mu - 1 - \lambda \frac{d\mu}{d\lambda} \right) D = 0, \quad \dots \dots \dots (9)$$

in agreement with (5).

XXXIV. *On Momentum in the Electric Field.* By J. J. THOMSON, M.A., F.R.S., *Cavendish Professor of Physics, Cambridge* †.

I HAVE for some years made considerable use of the principle proved in ‘Recent Researches,’ p. 9, that momentum as well as energy is distributed throughout the electromagnetic field, and that changes in the momenta of magnets, of circuits conveying electrical currents, and other material systems in that field are accompanied by equal and opposite changes in the momentum of the field itself. Thus

* ‘Theory of Sound,’ § 191, 1877.

† Communicated by the Author.