Some New Cases of Interference and Diffraction

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Radium rays may be inserted provisionally between Light-shock and Lamplight in the above order.

Conclusions.

1. The density of the image produced on a plate by exposure to radium rays (β and γ) increases to a critical value and then decreases, at first rapidly and afterwards very slowly, until a time is reached when the image is totally reversed.

2. Spark-images are at first obliterated by radium rays which do not cause such a great density as that of the spark-images obliterated.

3. With prolonged exposure radium rays reverse spark-images.

I am greatly indebted to Mr. Hayles, of the Cavendish Laboratory, for carrying out many of the experiments described in this paper.

XII. *Some New Cases of Interference and Diffraction.* By
R. W. WOOD, *Professor of Experimental Physics, Johns
Hopkins University* *.

[Plate IX.]

IN the following paper I propose to discuss certain types of the interference of light which have been known for many years, as well as some cases which, so far as I know, are quite new; the colours of mixed plates and the phenomena of interference in transparent films deposited on metallic reflectors being the cases chiefly considered. Several years ago it occurred to me that it would be worth while to try to devise some permanent film which would show Newton's colours under the most favourable conditions, and the cases cited in the present paper are, for the most part, the outgrowth of experiments made in this direction. The facts which have been brought out may be summed up as follows.

* Read January 22, 1904.

Diffraction "Parhelia."

State of Polarization along the fringes.

The colours of mixed plates are due to diffraction, and should not be classed with interferences in thin films. The explanation originally given by Young, and the treatments given by Verdet and others, are unsatisfactory, in that they do not indicate what becomes of the energy.

In the cases of films deposited on perfectly reflecting surfaces which, according to the elementary theory, should exhibit no interference-colours, we may, under certain conditions, have colours far more brilliant and quite as saturated as any shown by the soap-bubble. In other cases, where at first sight no interference appears to have taken place, we may, by employing polarized monochromatic light, obtain fringes of a very curious nature, which are the result of the interference between the elliptical vibration coming from the metal surface and the plane-polarized vibration reflected from the surface of the transparent film. We will go back now to the earlier experiments.

Preparation of Films for the exhibition of Newton's Colours.

In the case of a thin transparent lamina, such as a soap-film, the amplitudes of the disturbances reflected from the two surfaces are equal, and consequently completely destroy each other when the phase-difference is 180° . Inasmuch, however, as only a small percentage of light is reflected from each surface, the colours, though saturated, are not as intense as is desirable. In the course of some experiments with selenium I found, if a plate of mica is pressed against a pool of the molten substance on a glass plate, and the whole allowed to cool under pressure, that on stripping off the mica, films of mica of variable thickness were left upon the surface of the selenium, which showed Newton's colours of great beauty, arranged in mosaics. The patches of equal thickness being sharply bounded by straight lines, present an appearance similar to that of selenite-films under the polariscope. The selenium has a much higher refractive index than the mica, consequently the reflexion at each surface is the reflexion of rays incident from a rare to a denser medium, and the difference of phase is given by the difference of path alone; *i.e.*, we do not have the loss of half a wave-length due to

reflexion under opposite conditions, as would be the case if the mica films were in air.

If the mica is cemented to the plate with sealing-wax or any of the common resinous cements, very little trace of the colours is to be seen, owing to the fact that the refractive indices of the two media being so nearly the same, practically no energy is reflected from the boundary. The use of selenium can be avoided by very lightly silvering the surface of the mica, which may then be cemented to the glass with any good laboratory cement, the metallic layer taking the place of the medium of high refractive index. This latter method is the best for the preparation of large mosaics suitable for lantern-projection. In the patches which show no colour by reflected light, the interference may be detected with a small spectroscope, the spectrum appearing crossed by black bands, corresponding in position to the wave-lengths absent in the reflected light. Still more brilliant films can be prepared by first thickly silvering the mica, cementing the silvered side to the glass plate, and then stripping the mica off. The colours are scarcely visible, owing to the disproportionality between the amplitudes of the two interfering streams of light, but appear as soon as the upper surface of the mica is half-silvered, which can be done by immersing the plate in a silvering solution until the colours reach their maximum brilliancy. To obtain films which show the maximum brilliancy, it is clear that the amplitude of the stream reflected from the first surface must have the largest possible value consistent with the fulfilling of the condition that it be completely destroyed by the disturbance coming from the second surface when the phase-difference is 180° .

In the case of transparent films, the wave-lengths absent in the reflected light appear in excess in the transmitted light, there being no destruction of energy. If the second surface is a perfect reflector, the energy thrown down upon it by interference at the first surface will all be returned. If we consider the upper metallic surface as nonabsorbing, and work out the case by the method of multiple reflexions, we find that no colour will be produced, light of all wave-lengths being reflected with equal facility. The fact that

brilliant colours appear, means that light is absorbed at one or both of the silvered surfaces, since this is the only way in which the energy of the absent wave-lengths can disappear. If we assume a certain percentage reflected and a certain percentage absorbed by the thin silver film, we find that the waves for which the phase-difference is 180° are compelled to make more transits through the film than those for which the phase-difference is 360° . It is possible to obtain experimentally a condition in which the former are almost completely absent in the reflected light, while the latter are reflected with scarcely any loss of intensity. To calculate the most favourable conditions, we should require data regarding the percentages reflected and transmitted by films of various thicknesses.

It next occurred to me to substitute a thin film of collodion for the mica, half-silvering the film as before.

A sheet of glass can be silvered chemically, or procured by removing the varnish from the back of a piece of modern mirror-glass with alcohol. The silver film is then flowed with collodion diluted with three or four parts of ether. As soon as the film dries colours appear, contrary to theory. These colours may be quite brilliant, and are due to diffraction, as I shall show presently. If the plate be now immersed in Brashear's silvering-bath, the colours will instantly disappear, owing to the fact that the collodion-film and the solution have nearly the same refractive index. As soon as the silver begins to deposit, the colours reappear and increase rapidly in intensity. The bath should be rocked, the process being similar to the development of a negative. A little experience will enable the moment of maximum brilliancy to be correctly judged, when the plate should be immediately removed from the solution, washed, and dried. It is well to provide the plate with a cover of glass mounted over it at an angle of 20° , the whole forming a prismatic box. The object of inclining the cover is to get rid of the light reflected from it, which would otherwise dilute the interference colours. Plates prepared in this way show a wonderful blaze of colour and make excellent preparations for the lantern.

The Colours of Mixed Plates.

Interference colours of this type were discovered by Young, and described in the 'Philosophical Transactions' for 1802. They were subsequently studied by Sir David Brewster. Verdet and other writers on Optics have classified them with Newton's thin-film colours, and have given treatments which are not very rigorous and fail to show where the energy goes to.

The colours are very easily obtained by pressing a little white of egg between two pieces of plate-glass, separating the plates and squeezing them together a number of times so as to form a froth. The plates are to be pressed firmly together with a rotary sliding motion just before the froth becomes sticky, enclosing a film made up of air and albumen in the form of a mosaic. The colours are best seen by holding the plate towards a window or other bright source of light on a dark field. Certain wave-lengths will be found to be absent in the directly transmitted light. Young's explanation was that the path-difference between a ray passing through an air-space and one passing through the albumen was an odd number of half wave-lengths for such colours as failed to appear in the transmitted light. Neither Young nor subsequent writers, so far as I have been able to find, show what becomes of these absent colours, though both Young and Brewster observed the coloured fringes which appeared in the dark background to one side of the source of light. Brewster published a paper in the 'Philosophical Transactions' for 1837 in which he referred the colours to diffraction, though his treatment was not very complete, and concerned chiefly the case of diffraction by a transparent lamina bounded by a straight edge. Verdet objected to this explanation on the ground that the colours are independent of the size and arrangement of the air-bubbles, depending only on the thickness of the albumen-film and the angle of incidence. The interference phenomena of mixed plates are easily explained by the elementary theory of diffraction, and they should be classed with laminary diffraction effects, and not with thin film interferences, as is usually the case.

The following treatment may not be new, but I do not remember to have seen it anywhere:—In fig. 1 (Pl. IX.) let AA represent the glass plates with the albumen and air elements between them. We will assume the thickness of the albumen such that green light suffers a retardation of $\frac{\lambda}{2}$ in traversing it. If B is the lens of the eye, and parallel rays traverse the plate, the secondary disturbances represented by the dotted lines (normally diffracted rays) will be brought to a focus at E; that is, the reduced paths of all these rays are equal and the disturbances arrive at E in the same phase, if there be no retardation. The disturbances coming from the albumen elements are retarded, however, and reach E half a wave-length behind the disturbances coming from the air elements. The two sets destroy each other at this point, and green light will not be represented here. In general, light will be absent at this point if the retardation of a ray passing through albumen with respect to one passing through the adjacent air-space is $(2n+1)\frac{\lambda}{2}$. If the film is fairly thick, this condition may hold for a number of colours in the spectrum, which will consequently be absent in the image of any source of light seen through the plate. The question now is: What becomes of this energy? In the case of thin film interferences, the wave-lengths absent in the transmitted light appear in the reflected. This is not the case with mixed plates, which show no colour by reflexion. If we refer to fig. 1, it is clear that if we take parallel rays diffracted in an oblique direction, the phase-difference introduced by the retardations in the mosaic may be compensated by the obliquity, the agreement of phase being more or less complete for green light in the point F. The case is analogous to a laminary grating, which yields coloured central images, the absent wave-lengths appearing in the spectra. Mixed plates throw the light absent in the direct image into a halo or ring, which is seen to surround the source of light. Laminary diffraction phenomena produced by straight edges, two parallel slits, and gratings are very fully treated in Verdet's 'Optics.'

Mixed plates belong to the same class, the case being best defined as laminary diffraction by a great number of irregularly distributed transparent disks. If the patches of the mosaic were of uniform size, the halo would be fairly sharply defined and separated from the direct image by a dark space, which would become wider as the size of the elements of the mosaic decreased. Though I have succeeded in obtaining very perfect halos in some cases, separated by a dark area of considerable size, the variation in the size of the elements usually causes the halo to take the form of a disk, the centre of which is occupied by the direct image.

If the plates are held close to the eye and a distant lamp-flame viewed through them, the flame will, for example, appear purple and the surrounding halo green. If a small sodium flame is employed, parts of the mosaic will show it much blurred, and surrounded by a halo, while other parts, where the retardation is a whole number of half-waves, show it perfectly sharp and distinct. The distribution of the light in the halo depends on the form of the elements of the mosaic. By pressing the plates firmly together and sliding one over the other, the circular air-bubbles can be deformed into ellipses. The light in the ring will be more or less concentrated on opposite sides of the halo. If the ellipses were drawn out indefinitely, we should pass over to the grating, and the points of concentration would become first-order spectra, the rest of the halo disappearing.

I observed a very curious and interesting example of this concentration of light in a halo a number of years ago, while copying some diffraction-gratings on bichromatized albumen. The original grating was ruled on glass, 14,400 lines to the inch, a spacing so fine that copies were only obtained with considerable difficulty.

Some of the films were found to have frilled in the process of washing, the buckling of the film following the grooves of the grating to a certain extent. The albumen surface was seen by the microscope to have frilled into oval patches of varying length, but of fairly constant width, the width being equal to three lines of the original grating. In fig. 2 (Pl. IX.) we have a diagram illustrating this condition. This plate when held before the eye showed a ring of wide aperture

surrounding a brilliant source of light, with four distinct concentrations, two very bright and two quite faint. The appearance reminded one most forcibly of a solar halo with parhelia or mock suns. A photograph of this curious diffraction pattern was made by directing a camera towards a brilliant point source of light, and placing one of the frilled plates before the lens. This photograph is reproduced in fig. 3 (Pl. IX.).

The arrangement of the colours in the "mock-suns" produced in this way is, however, exactly the opposite of the arrangement in the real ones, which makes it appear doubtful if there is any connexion between the two. It is possible, however, that the usual treatment of parhelia could be improved by considering diffraction as well as refraction, as has been done in the case of the rainbow.

On the Polarized Fringes produced by the interference of two streams of light polarized at right angles.

In the case of ordinary thin-film interferences the planes of vibration of the disturbances reflected from the two surfaces of the film are parallel.

It is possible, however, to prepare a film which shall fulfil the requirement that the vibrations reflected from its upper surface make any desired angle with those coming from the lower surface. The path-difference between the two streams will vary with the thickness of the film; and if the amplitudes be equal we shall have the vibrations compounding into circular elliptic or plane ones, according to their phase-difference.

A thin glass or gelatine film, backed by a metallic reflecting surface, is all that is necessary. The incident sodium light should be polarized at an angle of 45° with the plane of incidence by passage through a nicol, and the reflected light examined with an analysing nicol. The fringes obtained in this way present a most curious appearance, reminding one forcibly of a spectrum line with a fainter component seen in the Fabry and Perot interferometer. Their general appearance is shown in fig. 4, which represents the fringes obtained by flowing a plate of speculum metal

with a rather dilute solution of gelatine, and allowing it to dry in a slightly inclined position.

The easiest way to get them, however, is to blow out the end of a rather large glass tube into a large thin balloon of tissue glass, picking out a portion, by the light of a sodium flame, which shows fairly straight interference-fringes two or three millimetres apart. A small piece of the thin glass is laid, with its slightly convex side down, upon a clean mercury surface, and sodium light, polarized in azimuth 45° , reflected from the surface at an angle of about 60° . On viewing the reflected light through a nicol, the curious double fringes can be found easily by slowly turning the nicol. The light will be found to be plane-polarized along the lines 1, 3, 5, 7, &c. of fig. 4, though in general the planes of polarization along one set of lines is inclined to the plane of polarization along the alternate lines, as is indicated below the figure, the arrows representing the direction of the vibration (electric vector). Between the lines of plane-polarized light, which appear as dark fringes when the nicol is so oriented as to extinguish the light, we have either elliptically or circularly polarized light, as can at once be shown by the introduction of a quarter-wave plate, which enables us to extinguish the light along the lines 2, 4, 6, and 8 by suitable adjustment of the mica plate and analyser. The direction of revolution of the vibration along lines 2 and 4 is opposite to that along lines 6 and 8.

I at first attempted to work out the problem by compounding a plane-polarized vibration, coming from the air-glass surface, with a nearly circular vibration coming from the metal. This was a failure, but it at once occurred to me that owing to the refraction by the glass or gelatine, the incidence-angle of the light falling upon the metal would be too small to produce circular polarization.

It seemed best, upon the whole, to determine experimentally the exact nature of the vibration coming from each surface, and then to try whether, by compounding them with various phase-differences, the observed results could be accounted for.

The incident light vibrated in a plane indicated by the arrow at the top of fig. 4. The light reflected from the

glass surface is of course plane-polarized, vibrating parallel to the surface when the angle of incidence is equal to the polarizing angle. For larger angles of incidence, the plane of the reflected vibration makes an angle with the surface, depending on the magnitude of the reflected component, which lies in the plane of incidence. To determine the nature of the vibration coming from the glass-metal surface, it was necessary to get rid of the light reflected from the upper surface of the glass. This was done by laying a small piece of rather thick plate-glass on a plate of speculum metal with a film of benzole between, and allowing a narrow beam of light to fall upon the surface of the glass. The images reflected from the two surfaces appeared separated, and could be independently examined with a nicol. The benzole film practically brought the metal surface into optical contact with the glass. The reflected beams were found to be plane-polarized, the vibrations being in the directions shown in fig. 5 *a*, for an angle of incidence near the polarizing angle. As the angle of incidence increased, the planes of the two vibrations both turned towards the vertical, and finally made an angle of 90° with each other, *i. e.* 60° and 30° with the reflecting surface.

If we compound the two components shown in fig. 5 *a* with varying phase-differences, we can account easily for the polarized fringes. In fig. 5 *b* let BC be the vibration from the glass and BA that from the metal. When the path is zero or a whole number of waves, we have the plane-polarized resultant BE. If the path-difference is an odd number of half-waves, we have the plane-polarized resultant BF. These two states occur along the lines 1, 5 and 3, 7 respectively. The angles which the planes of vibration make with the reflecting surface should be respectively greater and less than the angle made by the component coming from the metal, as was found to be the case. As we increase the angle of incidence the component BC (from glass) increases in magnitude and turns up towards the vertical, the inclinations of the planes of polarization of the two sets of fringes to each other becoming greater.

Between the lines along which the light reflected from the film is plane-polarized, we have lines of elliptically (or in

some cases circularly) polarized light. The directions of revolution were determined with the quarter wave-plate, and are as shown in fig. 4. Geometrical computations of the elliptic vibrations, resulting from two components such as are shown in fig. 5 *b*, agreed perfectly with the experimentally determined orbits, both in respect to the directions of the major axes and the directions of rotation. The method used was similar to the one given in Müller-Pouillet's text-book (vol. ii. 1. p. 1135), the only modification necessary being the rotation of one of the sets of parallel lines, which represent displacements, through a certain angle, since, in the case with which we are dealing, the two components are not at right angles. By sufficiently increasing the incidence-angle the components AB and BC can, however, be brought to very nearly a right angle. At the same time the intensity of the component from the glass surface has increased to such a degree as to be about equal to the one from the metal, and we have practically circular polarization along certain lines.

A careful study of these fringes makes a most excellent exercise for advanced students in Optics. The conditions under which they are obtained are very simple, and I consider their study far more instructive than the mere inspection of a collection of crystal sections in a polariscope arranged for convergent light.

Colours of Frilled Transparent Films on Metallic Surfaces.

We will now consider a remarkable case of interference which appears to be essentially different from any of the cases which have been previously studied. The theory of thin films shows, as Lord Rayleigh points out in his article on "Wave-theory of Light," that a transparent film on a perfectly reflecting surface shows no interference-colours. As I have already pointed out, a thin film of collodion deposited on a bright surface of silver shows brilliant colours in reflected light. It moreover *scatters* light of a colour complementary to the colour of the directly reflected light. This I find is due to the fact that the collodion film "frills,"

the mesh, however, being so small that it can only be detected with the highest powers of the microscope. Commercial ether and collodion should be used. If chemically pure ether obtained by distillation is used, the film does not frill, and no trace of colour is exhibited.

In the cases of the transparent films with the first surface lightly silvered, the second heavily coated, the waves absent in the reflected light are absorbed by the metal, as I have already shown. In the present case these waves are scattered by the granular surface. If a spot on the film which appears purple by reflected light is illuminated with sunlight, it will be found that green light is scattered, not in all directions, but through a range corresponding to the size of the granulation, as in the case of mixed plates.

If the light is incident normally, the scattered light comes off through an angular range included between ten and thirty degrees, and again at an angle of nearly 90° , the latter being strongly polarized. Conversely, if the sunlight be incident at nearly 90° , strongly polarized light is scattered normally. Considerable difficulty has been found in explaining these colours satisfactorily. They appear to be saturated, *i. e.* certain wave-lengths are completely absent in the reflected light, and until the granulation was detected with the microscope it was impossible to make even a satisfactory hypothesis. Even now the polarization effects are difficult to account for.

At first sight it may seem as if the colours could be classed with the phenomena of mixed plates, their brilliancy and saturation reminding one of the appearances produced by laminary retardation. The films, however, show no colour by transmitted light when deposited on glass, and the effective doubling of the retardation, by the reflexion back through the film by the metal surface, can hardly account for the observed effects. Moreover, the energy stream reflected from the surface of the collodion appears to be essential, for if we employ light polarized perpendicular to the plane of incidence, and set the plate at the polarizing angle of collodion, so that no reflexion occurs except at the metal surface, all trace of colour disappears. If the angle of incidence is larger than the polarizing angle, the colour of

the reflected light changes to its complementary tint when the plane of polarization is made parallel to the plane of incidence. As I have shown in the preceding part of this paper, the effects at large angles of incidence involve the interference of two streams of light polarized in planes inclined at 90° to each other, which are complicated enough with monochromatic light and structureless films. For the present only normal incidence will be considered. Though I know of no direct way of proving that, in this case, the light reflected from the collodion surface is an essential factor, there is strong indirect evidence.

If the film is wedge-shaped and sodium light is employed, the dark fringes seen at normal incidence move towards the thick edge of the wedge as the angle of incidence is increased, exactly as they do with thin films of the ordinary type. If the incident light is polarized perpendicularly to the plane of incidence, the fringes gradually fade out, disappearing at the polarizing angle. This indicates that they are produced in the same way at normal incidence as at the polarizing angle, namely, through the agency of light reflected from the surface of the collodion.

If we consider some value of λ , for which the path-difference between the rays reflected from the collodion and metal surfaces amounts to an odd number of half-waves, the colour corresponding to this wave-length will be weakened in the reflected beam owing to interference. In the case of transparent thin films the absent colour appears in excess in the transmitted light, while in the present case it is thrown back through the film by the metal surface. It is thus clear that the colours which are weakened in the reflected light are made to traverse the frilled film a greater number of times than the colours for which the path-difference is an even number of half-waves.

This accounts for the fact that these colours are more strongly scattered by the granulations of the films.

A collodion surface only reflects about 5 per cent. of the incident energy; and it was found impossible to account for the strong colours seen in the reflected light, by compounding the feeble stream of light from the collodion with the powerful stream coming from the metal.

It appeared, however, that the observed effects could be accounted for, if the somewhat arbitrary assumption were made that the granulated surface reflected more strongly than a smooth surface. As I have already said, the granulations are too small to interfere with the regular reflexion of light, the scattering being selective, so to speak, *i. e.* confined to the waves which, owing to interference, are compelled to traverse the film a number of times.

The assumption above referred to appeared to be too arbitrary to make without some experimental evidence, and experiments were therefore made to determine the effect of the "frilling" of the film on its reflecting power. One of the faces of a 60° prism of crown glass was flowed with collodion of the same dilution as that used in the preparation of the coloured films. It showed in reflected light interference-colours, which, however, were very much diluted with white light, owing to the small difference between the refractive indices of the two media. In working with the film on silver it was found that, if the colours did not appear at once, as soon as the film dried, they could be brought out by breathing on the film, the deposit of moisture being advantageous to the formation of the granulations. It was always possible to intensify the colours in this way. The film deposited on the surface of the prism was treated in this way, one half of it being screened from the deposit of moisture by a plate of glass. As soon as the moisture had evaporated, it was found that the reflecting power of the surface had been greatly increased, the film appearing almost as bright as a half-silvered surface.

The increase in the brilliancy of the reflected light was about three-fold, as was shown by covering the unfrilled portion with a sheet of thin glass, which about equalized the intensities. In other words, the frilled collodion-surface regularly reflects white light, of an intensity very nearly equal to that of light reflected from thin glass surfaces.

On examining the granular surface with polarized light, it was found that the angle of maximum polarization was in the neighbourhood of 63° , which would make its refractive index about 1.96. The polarizing angle of the smooth collodion was about 56° , the corresponding refractive index being 1.48.

An attempt was made to determine whether the granulation gave rise to elliptical polarization, the abnormal value of the refractive index suggesting the properties of the surface-films, which play such an important part in the theory of elliptical polarization. No decisive results were obtained, for though the phenomenon was found, it seemed impossible to eliminate the component reflected from the collodion-glass surface, which, as I have shown, may, by interference with the component reflected from the air-collodion surface, give rise to an elliptical vibration.

The interferometer failed to show any change in the refractive index as the result of frilling, which indicates that the effect is confined to the surface. A film deposited on glass of such thickness as to produce a shift of half a fringe width (sodium light) was frilled by moisture, one half being protected by a glass plate. No shift was found at the line of demarcation, as would have been the case if the refractive index of the film had been raised from 1.48 to 1.96 throughout its entire thickness.

It is my plan to make a further study of the apparent effect of the granulation on the refractive index of the surface, by the method of total reflexion.

DISCUSSION.

Mr. JULIUS RHEINBERG said Prof. Wood's paper had been of special interest to him, in particular as he found in it confirmation of the results afforded by some experiments he had made some time ago. He thought it was not generally known that some striking examples of the colours of mixed plates were to be found in Nature. A few years ago there had been some discussion in the Quekett Microscopical Club as to the origin of certain brilliant colours shown by the diatom *Actinocyclus Ralfsii* when seen with an objective of small numerical aperture, these colours being altogether absent when an objective of large numerical aperture was used. From an optical point of view, the diatom-valves in question might be looked upon as plates of colourless siliceous material perforated by numerous tiny holes.

Searching for the cause of the colour phenomena, it was

found, on viewing the diffraction effect which the object produced in the upper focal plane of the objective when a narrow cone of light from the condenser was used, that the central dioptric beam (or, as Prof. Wood termed it, the normally diffracted beam) was *coloured* instead of white, whilst the laterally diffracted rays, instead of appearing in the usual spectrum colours, were differently tinted. The dioptric beam was always of the same colour as the diatom when viewed with the narrow-angled objective, and it occurred to him, that therefore the image formed solely by the beams diffracted laterally ought to be of the complementary colour. To test the matter a circular glass disc was made, consisting of a tiny circular disc with plane parallel surfaces, inserted in the centre of a larger disc slightly prism-shaped in section. When this was placed over the wide-angled objective, it had the effect of displacing the image formed by the rays which

Section of Double-Image Disc.

passed through the peripheral part of the disc, with regard to the image formed by rays passing through the central part, so that two images of each diatom were formed side by side. The one image was due to the dioptric beam only, the other to the laterally diffracted rays only. It was, in fact, just the same as if two objectives—one a narrow-angled one, the other a wide-angled one—were being used on the same object at the same time. He had at the time explained this matter as being a natural case of the colours of mixed plates*, and was pleased to find the further confirmation of that view afforded by Prof. Wood's interesting paper.

A number of specimens of *Actinocyclus Ralfsii* of various colours were on view under the microscope—some blue,

* *Vide*: "The Origin of Certain Colour Phenomena typically shown by *Actinocyclus Ralfsii*," Journal of the Quekett Microscopical Club, 1901, pp. 13-24, and "Note on Double-Image Discs and Complementary Interference Colours," *id.* 1901, pp. 151-152.

some green, and some yellow. In all cases, the second image, formed by the laterally diffracted beams, which was seen at the side of the first one, was of the complementary tint. By closing an iris diaphragm which was fixed just over the objective, these second images could be cut out, leaving only the first ones visible. The objective used was an 8 mm. apochromatic of $\cdot 65$ N.A. An auxiliary lens was arranged so that it could be brought rapidly in position over the eyepiece of the microscope; by this means, the diffraction effects produced by the object in the upper focal plane of the objective (which are repeated in the Ramsden circle of the eyepiece) could be conveniently examined alternately with the object itself.

XIII. *A Quartz-Thread Vertical Force Magnetograph.* By W. WATSON, A.R.C.S., D.Sc., F.R.S., *Assistant Professor of Physics at the Royal College of Science, London* *.

[Plates X. & XI.]

THE late Dr. Eschenhagen was the first to show that when the moment of inertia of the suspended system in a horizontal-force magnetograph is made very much smaller than that employed in the ordinary form, it is possible to detect variations in the earth's field of quick period. Since the study of these short-period variations promises to be of considerable interest, the design of self-recording instruments capable of giving satisfactory records becomes of importance. Both Dr. Eschenhagen † and the author ‡ have described forms of apparatus suitable for recording the variations of the declination and horizontal component. The design of a satisfactory form of instrument to record the rapid variations of the vertical component presents, however, some very considerable difficulties. Thus, if the attempt is made to reduce to any great extent the moment of inertia, and hence the mass, of the balanced magnet in the ordinary form of Lloyd's

* Read February 26, 1904.

† 'Terrestrial Magnetism,' v. p. 59 (1900).

‡ Ibid. vi. p. 187 (1901).