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ON THE PLANENESS OF INTERFEROMETER PLATES

BY

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Introduction.

Highest precision is claimed by those optical surfaces which are used for producing interference fringes in different kinds of interferometers. While ordinary optical surfaces are regarded as being satisfactory when the deviations from the wanted form (spherical, plane etc.) are smaller than $^1/_4$—$^1/_5$ of the wavelength of the light to be used, it is generally expected that the deviations from planeness of good interferometer plates may not exceed $^1/_{40}$—$^1/_{50}$ wavelength, *i. e.* the plates should be ground to a precision of 10^{-5} mm. This is particularly the case when the plates are destined to the use in an interference spectroscope for separating very close spectrum lines as, for example, in investigations of hyperfine structure by means of the Fabry-Perot étalon. The resolving power of this instrument depends, by a given plate distance, on three factors, *viz.* the planeness of the surfaces, the reflecting power of the silver film, and the precision of the adjustment to parallelism. Usually, the resolving power will be a result of all three factors acting together.

Most experimenters working with the Fabry-Perot étalon may be satisfied with obtaining the required resolving power by varying the distance of the plates and the thickness of the silver film, realizing neither how good the plates are nor to what degree the deviation from exact planeness may influence the resolving power. This standpoint is probably due to the facts that no simple methods of examination of the plates have so far been available and, primarily, that the physicist is unable to improve his plates by grinding.

In this paper simple methods will be described for testing of interferometer plates and for separately examining the different factors on which the resolving power depends.

Methods for Testing of Interferometer Plates.

For examining the planeness of interferometer plates only methods of highest sensitivity are available, *i. e.* methods depending just on interference. It should be expected, therefore, that an examination of the interference fringes produced by the interferometer itself could give some information. The testing of the planeness of a surface is carried out by using the Fizeau fringes of equal thickness formed in a thin wedge-shaped air interspace between the surface and a standard flat, when illuminated by monochromatic light. As the interval e between two consecutive fringes corresponds to a variation of $\frac{\lambda}{2}$ of the thickness of the air interspace, a deviation ε of a fringe from a straight line implies that the surface in the point concerned deviates from planeness with $\frac{\varepsilon}{e} \cdot \frac{\lambda}{2}$. In measuring the deviations of the fringes from linearity and equidistance it is possible thus to give a quantitative statement of local deviations from planeness as used in optical workshops and often mentioned in the literature[1].

Such an examination could of course conveniently be carried out by means of the great technical interferometers which were recently built for this purpose[2]; these instruments, however, are too expensive for ordinary physical laboratories. It is possible, nevertheless, by simple means to improvise an instrument allowing us to make measurements with the same accuracy as with the said great interferometers, if only a pair of suitable lenses is available. Such an arrangement, which has been used in this laboratory for a preliminary testing of unsilvered interferometer plates, is to be described in the following.

In the left part of Fig. 1 is shown a schematic design of the apparatus. The light from the light source L (an Osram spectral lamp) is concentrated upon the diaphragm B_1 by means of the condensor C and is then made parallel by the objective O_1. After passing a half-silvered glass plate G making an angle of 45°, the

[1] F. Kohlrausch, Praktische Physik. 17. Aufl. p. 408, 1935.
E. Einsporn, ZS. f. Instrkd. **57**, 265, 1937.
C. G. Peters and H. S. Boyd, Journ. opt. Soc. **IV**, 407, 1920.

[2] R. Landwehr, ZS. f. Instrkd. **62**, 73, 1942.
O. Schönrock, ZS. f. Instrkd. **62**, 357, 1942.

beam will hit perpendicularly upon the thin air layer between the two unsilvered interferometer plates *F—P*. The reflected beam will then be reflected at a right angle by the plate *G*, passing through a second objective O_2, in the focal plane of which the diaphragm B_2 is placed, through which the interference fringes can be observed. As objectives O_1 and O_2 were applied two achromatic lenses with an aperture of 65 mm. and with the focal lengths 700 and 400 mm., respectively, belonging to the Steinheil

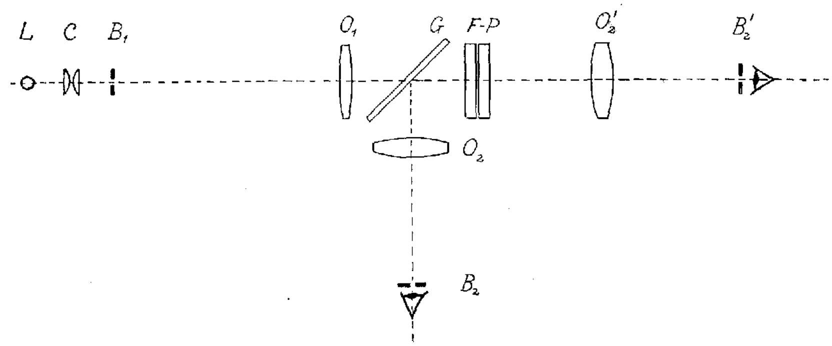

Fig. 1.

glass spectrograph *GH*. The circular diaphragm B_1 could be diminished to 0.5 mm. in diameter, giving a sufficient parallelism of the beam also at greater thickness of the air interspace. The diaphragm B_2, having a diameter of 2 mm., served only for fixing the eye position and for removing the light reflected from the front and back of the pair of plates. B_2 could be replaced by a camera in order to photograph the fringes. This arrangement was easily constructed by means of two optical benches, placed perpendicular to each other.

As a holder for the interferometer plates served the Fabry-Perot étalon itself with a distance ring of 1 mm. thickness. The étalon was of the same type as the construction by Carl Zeiss, as developed by G. Hansen. The plates were delivered by Bernhard Halle, Berlin. The use of the Fabry-Perot étalon as a holder for the plates involves a very easy adjustment of the air layer perpendicular to the beam by means of the adjusting screws of the instrument and, moreover, a convenient adjustment of the wedge angle of the air layer by means of the three screws working upon elastic tongues. A rapid setting of the wished fringe distance is obtained, and the interference pattern is widely insensitive against vibrations.

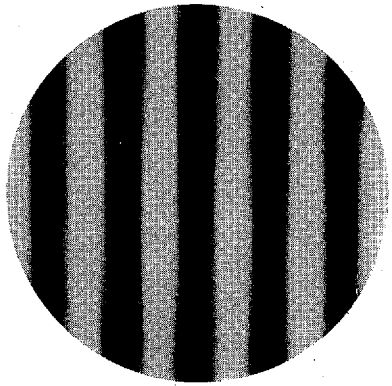

Fig. 2. Fizeau fringes by unsilvered plates. d = 1 mm. Cd 6438.

Fig. 2 is a reproduction of a photographic negative of the interference fringes from a pair of fairly good quartz plates taken with the light of the red *Cd*-line 6438 A.U. As there was no standard flat in this arrangement, only relative measurements could be obtained. The accuracy in the determination of planeness by means of this method does not exceed 10^{-5} mm., or $^{1}/_{50}$ wavelength, being limited by the diffuseness of the fringes, which does not permit to measure them more accurately than $^{1}/_{25}$ of the interval of the fringes.

The accuracy obtained is thus limited due to the fact that the fringes are produced only by two reflected beams giving very diffuse fringes. It is therefore tempting to test the planeness with silvered plates in order to profit by the highly increased sharpness of the fringes caused by the great number of cooperating reflected beams. Actually, one cannot anticipate whether the silvering will change the form of the surface. However, in the case of the Fabry-Perot plates, this procedure may be justified since they are employed only after coating with silver and, therefore, only the optical planeness of the silver film is of interest.

At the degree of silvering (reflecting power about 90 $^{0}/_{0}$) generally applied to the Fabry-Perot plates, it appears inconvenient to observe the fringes produced by reflected light, since the beam reflected from the first surface is much stronger than the following reflected beams. Therefore, sharp dark fringes are obtained against a bright background, the contrast being rather insufficient. On the other hand, when the light passes through the plates, disturbances caused by reflected light are avoided, and an image appears, complementary to the first, consisting of sharp bright lines against a dark background. This image is very suitable for the purpose in question.

An arrangement for qualitative testing of silvered interferometer plates based on this principle has been proposed by M. DUFFIEUX[1] and could easily be improved in such a way as to allow quantitative measurements.

The above described apparatus for testing the unsilvered plates could easily be extended to test the silvered plates[2], as indicated in the right part of Fig. 1. As the interference fringes should be observed by transmitted light, it was found convenient to arrange the optical parts simply along an optical bench of a length of 2 m. The glass plate G was removed, and the Fabry-Perot étalon with an 1 mm. distance ring between the silvered plates was placed in the parallel beam from the collimator B_1O_1. The objective O_2 was then moved to O_2', and the diaphragm B_2 to B_2', as shown in the figure. The interference fringes were observed through B_2', using O_2' as a magnifier in order to obtain a sufficient field of view. B_2' was placed in the focus of O_2', and in order to secure that the image was formed in infinity, the étalon was placed in the second focal plane of O_2'. B_2' could again be replaced by a camera adjusted to infinity (a 9×12 cm. plate camera with 13.5 cm. focal length). The aperture of the camera lens had to be made so small that false reflexions were avoided.

The adjustment of the light beam to parallelism and of the air layer perpendicular to the beam was carried out by autocollimation, using the light reflected from the interferometer plates. This could be done very accurately both with unsilvered and silvered plates. In order to facilitate this adjustment the diaphragm B_1 was covered with white painting on its back side. A number of diaphragms with fixed diameters 0.5 — 1.0 — 1.5 — 2.0 mm. were used.

Fig. 3 shows a photographic negative of the fringes from strongly silvered plates taken with the 1 mm. distance ring and by the light from the *Cd*-line 6438 A.U. A comparison of this

[1] M. DUFFIEUX, Revue d'Optique **11**, 159, 1932.

[2] The silvering was carried out by evaporation in high vacuum according to R. RITSCHL'S method. ZS. f. Phys. **69**, 578, 1931.

picture with Fig. 2, taken with the same plates, indicates clearly the great improvement and the increased possibility of recognizing very small defects on the surface. Small irregularities in the fringes, which correspond to deviations of about $^1/_{50}$ wavelength and which could not be detected on Fig. 2, appear very clearly.

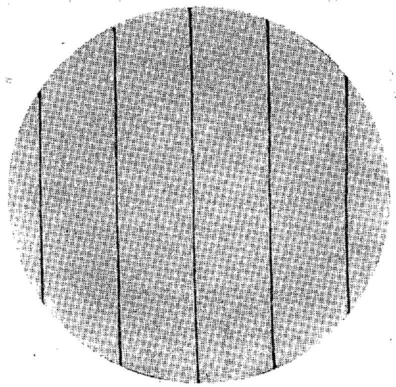

Fig. 3. Fizeau fringes by silvered plates: d = 1 mm. Cd 6438.

The determination of the errors of the plates was carried out by measuring the photographic exposures by means of a measuring microscope. Such measurements on repeatedly silvered plates led to the result that the errors of a given surface were not modified by the coating with silver, provided that a distance of at least 15 cm. was used during the evaporation of silver. For the best surfaces examined the greatest deviations from planeness were about $^1/_{50}$ wavelength.

The Accuracy in Determinations of Planeness.

Accuracy and sensitivity of the described measuring method for silvered surfaces depends primarily on the breadth of the interference fringes and, consequently, on the reflecting power of the silver film.

The intensity distribution within an interference fringe produced by an infinite number of reflected beams of monochromatic light is given by Airy's formula

$$I = \frac{I_0}{1 + \frac{4\varrho}{(1-\varrho)^2} \cdot \sin^2 \frac{\alpha}{2}}. \tag{1}$$

where I_0 is the maximum intensity, ϱ the reflecting power, and α the phase angle. This formula is, strictly speaking, valid only for Haidinger's interference rings formed in an exactly plane parallel air layer. However, it could also be used in the case of

FIZEAU's fringes produced in a wedge-shaped air layer, when the wedge angle is very small and therefore a sufficient number of beams are contributed.

In order to employ the Airy formula to a calculation of the intensity distribution in the neighbourhood of the maximum intensity of the fringe, it is convenient to replace the sine with the angle itself, which is a sufficient approximation[1]. Setting, at the same time, $I_0 = 1$, the formula is reduced to

$$I = \frac{(1-\varrho)^2}{(1-\varrho)^2 + \varrho \cdot \alpha^2}. \qquad (2)$$

The half intensity breadth (instrument breadth) of the fringes could then be calculated by putting $I = {}^1/_2$, giving in angle units

$$2\,\alpha_{0.5} = 2 \cdot \frac{1-\varrho}{\sqrt{\varrho}}. \qquad (3)$$

In estimating the accuracy of the measurement of planeness it is appropriate to introduce the relation half intensity breadth/fringe interval, which may be denoted as the relative half intensity breadth γ.

As one fringe interval corresponds to $\alpha = 2\pi$, we get for γ

$$\gamma = \frac{2\,\alpha_{0.5}}{2\,\pi} = \frac{1-\varrho}{\pi\sqrt{\varrho}}. \qquad (4)$$

This quantity obviously depends only on the reflecting power ϱ of the silver film. For values of ϱ from 0.85 to 0.95, the reciprocal value of γ is calculated in the following table.

ϱ	$^1/\gamma$	ϱ	$^1/\gamma$
0.85	19.3	0.91	33.3
0.86	20.8	0.92	37.7
0.87	22.5	0.93	43.3
0.88	24.6	0.94	50.8
0.89	26.9	0.95	61.2
0.90	29.8		

On the assumption that the accuracy in setting the cross-wires of the measuring microscope upon the fringes amounts to $^1/_{10}$ of the half intensity breadth, it will be possible to measure deviations

[1] Cf. H. C. BURGER and P. H. VAN CITTERT, ZS. f. Phys. **44**, 58, 1927. H. KOPFERMANN, Kernmomente, Leipzig 1940, p. 82.

from a straight line with an accuracy of $^1/_{10}\,\gamma$, *i. e.* if $\varrho = 0.9$, about $^1/_{300}$ of the fringe interval. As this interval corresponds to $\frac{\lambda}{2}$, an accuracy of $^1/_{600}$ wavelength or about 10^{-6} mm. can be obtained.

For the interference fringes formed by unsilvered plates the relative half intensity breadth is $^1/_2$, since the intensity distribution follows a pure sine curve. If the setting again can be done accurately to $^1/_{10}$ of the half intensity breadth, an accuracy of $^1/_{20}$ fringe interval or $^1/_{40}$ wavelength should be obtained in the determination of planeness. This is in accordance with the usual experience. When using silvered plates, the accuracy is thus increased 10 to 20 times.

The preceding considerations are only valid if the interference fringes really can be regarded as curves of equal thickness, *i. e.* if the angle of incidence is exactly constant. Although the measurements were performed at normal incidence, the finite area of the diaphragm of the collimator might cause a failure in the parallelism of the light beam[1]. If the beam contains all angles of incidence ranging from 0 to a small value β, it follows from the interference condition that the number of order must vary slightly. For a beam exactly normal to the air layer, the order of interference is $m_1 = \frac{2\,d}{\lambda}$ and, for a beam with the angle of incidence β, $m_2 = \frac{2\,d\cos\beta}{\lambda}$.

Then,

$$\varDelta m = m_1 - m_2 = \frac{2\,d}{\lambda}\,(1-\cos\beta) \text{ or, as } \cos\beta = 1 - \frac{\beta^2}{2},$$

$$\varDelta m = d\cdot\frac{\beta^2}{\lambda} \text{ or } \beta = \sqrt{\frac{\lambda\cdot\varDelta m}{d}}.$$

In order to avoid unsharpness caused by lack of parallelism of the light beam, $\varDelta m$ should be negligible as compared with the relative half intensity breadth γ. For $\varrho = 0.9$, we have $\gamma = {}^1/_{30}$. If we permit $\varDelta m = {}^1/_{100}$, we get for $\lambda = 5.10^{-5}$ cm. and $d = 0.1$ cm. that $\beta = 2.10^{-3}$. This condition is easily fulfilled at the applied focal length (700 mm.) of the collimator, if the diameter of the diaphragm does not exceed 2.8 mm.

[1] CH. FABRY, Revue d'Optique, 1, 445, 1922.

It should further be emphasized that, in the calculation of the half intensity breadth, it was assumed that the employed spectrum line was strictly monochromatic, while the real measurements are to be made with a line of finite breadth. If this natural line breadth is known, it is easy to estimate its influence upon the accuracy of the measurements. By differentiating the interference condition $m\lambda = 2d\cos i$ we get

$$\frac{\lambda}{\Delta\lambda} = -\frac{m}{\Delta m} \text{ or } |\Delta m| = m \cdot \frac{\Delta\lambda}{\lambda} = 2d \cdot \frac{\Delta\lambda}{\lambda^2}$$

for normal incidence. Δm must also here be small compared with the instrument breadth γ. Using the red *Cd*-line 6438 A.U., for which the natural half intensity breadth was measured to about 0.02 A.U., we get for $d = 0.1$ cm.

$$\Delta m = 2 \cdot 10^{-7} \cdot \frac{0.02}{6438^2} = \frac{1}{100},$$

which could be neglected compared with $\gamma = {}^1/_{30}$.

In order to be quite sure that the natural line breadth does not influence the measurements a distance ring as thin as possible should consequently be used; simultaneously, this involves a reduction in unsharpness which is due to the lack of parallelism of the light, as mentioned above. A distance ring of 0.5—1.0 mm. will be sufficient for this purpose[1]. Three strips of metal foils, 0.1 mm. thick, might also be applied, but they are not so easy to manage.

When using very thin metal sheets as distance spacers another source of error must be taken into account, *viz.* an increased danger of deformation of the interferometer plates due to unequal forces from the three adjustment screws. Such a deformation appears in the interference fringes which then lose their straight lined form and instead assume a characteristic fan-shaped appearance. With greater thickness the elasticity of the material will easier prevent great forces to arise.

Under proper conditions, however, it should be possible to obtain an accuracy in the measurements of planeness of at least

[1] See P. P. Koch, Ann. d. Phys. **42**, 1, 1913.

$^1/_{600}$ wavelength or 10^{-6} mm. This accuracy was actually attained by repeated measurements of small deviations from planeness.

The same accuracy should also be obtainable from all measurements based upon interference, when silvered plates are used.

The Dependence of the Resolving Power on the Planeness.

In order to estimate the influence of the errors in the surfaces on the resolving power of the Fabry-Perot plane parallel étalon it appears reasonable first to calculate the maximum resolving power, *i. e.* the resolving power obtained from ideal, faultless plates by collaboration of an infinite number of rays. The above derived expression (3) for the half intensity breadth (instrument breadth), which holds both for the Fizeau fringes and the Haidinger rings formed in the plane parallel layer, could be expressed in wave-numbers (cm.$^{-1}$) rather than in angle units, remembering that $\alpha = 2\pi$ corresponds to $\Delta\nu = \frac{1}{2d}$ cm^{-1}. We get for the half intensity breadth

$$\Delta\nu_{0.5} = \frac{1-\varrho}{2\pi d\sqrt{\varrho}}\ \mathrm{cm}^{-1}.$$ [1]

A preliminary value for the resolving power R is then obtained, assuming that two spectrum lines can just be separated, if their distance is equal or greater than the half intensity breadth.

$$R = \frac{\lambda}{\Delta\lambda_{0.5}} = \frac{\nu}{\Delta\nu_{0.5}} = \frac{2\pi d\sqrt{\varrho}}{\lambda(1-\varrho)}.$$

As is well-known, the half intensity breadth is unfit for this calculation, but, as shown by Lord Rayleigh, the line breadth should be used, for which $I = 0.4$, corresponding to a minimum in the resulting intensity curve of about 20 % of the maximum intensity[2]. For this line breadth we find, using Airy's formula (2), that $2\,\alpha_{0.4} = 2\cdot\sqrt{1.5}\cdot\frac{1-\varrho}{\sqrt{\varrho}}$

[1] H. Kopfermann, Kernmomente. Leipzig 1940, p. 82.
[2] W. H. J. Childs, Journ. scient. Instr. **3**, 97, 1926.

or, converted into wave-numbers, $\Delta\nu_{0.4} = \frac{(1-\varrho)\sqrt{1.5}}{2\pi d\sqrt{\varrho}}$ cm^{-1}, *i. e.* $\sqrt{1.5}$ times greater than the half intensity breadth $\Delta\nu_{0.5}$. The real maximum resolving power will then be $\sqrt{1.5}$ times smaller than calculated by means of $\Delta\nu_{0.5}$.

$$R = \frac{2\pi d\sqrt{\varrho}}{\lambda(1-\varrho)\sqrt{1.5}} \tag{5}$$

From this formula we get *e. g.* for $d = 0.5$ cm., $\lambda = 5.10^{-5}$ cm. and $\varrho = 0.9$ that $R = 500\,000$.

In order to estimate the smallest errors in planeness allowed, the interference equation $m\lambda = 2d\cos i$ should be differentiated, keeping m and i constant. We then find

$$\frac{\lambda}{\Delta\lambda} = \frac{d}{\Delta d} \text{ or } \Delta d = d\cdot\frac{\Delta\lambda}{\lambda} = \frac{d}{R}.$$

Replacing R by (5), we obtain $\Delta d = \frac{\lambda\cdot(1-\varrho)\sqrt{1.5}}{2\pi\sqrt{\varrho}}$.

This expression gives the error in planeness Δd which would cause a change in wavelength $\Delta\lambda$ corresponding to the maximum resolving power. The permissible errors should then be essentially smaller than the value Δd. The claims in planeness of the surface depend only on the reflecting power ϱ and increase strongly with ϱ. Thus, for $\varrho = 0.9$ and $\lambda = 5.10^{-5}$ cm. we get $\Delta d = 10^{-5}$ mm. $= {}^1/_{50}\,\lambda$ and for $\varrho = 0.95$ $\Delta d = {}^1/_{100}\,\lambda$.

In order to utilize fully such high reflecting powers, the deviations from planeness should consequently not exceed ${}^1/_{100}$—${}^1/_{200}$ wave-length. Also the adjustment of the étalon to parallelism should be carried out with the same precision.

Determination of the Maximum Resolving Power.

The maximum resolving power of the Fabry-Perot parallel plate étalon was determined experimentally in different spectrum regions. By the arrangement described for silvered plates in

Fig. 1, first an exposure of the Fizeau fringes was made by illumination with a spectrum line in the spectrum region in question, using so small a thickness of the air layer (f. ex. 0.1 mm.) that neither the natural line breadth nor the deficiency in parallelism of the light could play any part. Subsequently, a second exposure was made on the same plate under unaltered conditions and with the same time of exposure, but with only half the intensity of illumination, attained by means of a rotating sector placed in the parallel beam, between O_1 and F—P in Fig. 1. These two exposures were then measured by means of a Zeiss registrating micro-photometer, giving directly the relative half intensity breadth γ of the fringe.

The measurements gave values for γ constant for a given silver coating and independent of the thickness of the air layer, provided that it was smaller than a given value. The measured values for strong silverings were ranging from $^1/_{30}$ to $^1/_{50}$, as was to be expected for reflecting powers of about 0.9. The reflecting power of the surface was not measured, as the necessary equipment is unavailable at the present time.

By combining formulae (4) and (5), we get

$$R = \frac{2\,d}{\lambda \cdot \gamma \cdot \sqrt{1.5}}$$

by means of which the maximum resolving power R could be determined for every thickness d, using the measured value of γ.

For $\gamma = {}^1/_{50}$, $d = 0{,}5$ cm, and $\lambda = 5.10^{-5}$ cm, $R = 800\,000$ is found.

The Use of Fizeau Fringes in Spectroscopy.

The present interference spectroscopy is based upon the application of Haidinger interference rings for equal inclination, which are formed by plane parallel layers and are located in infinity. In the general interference condition $m \cdot \lambda = 2\,d \cos i$ this corresponds to a constant thickness of the air layer d, while the angle of incidence i is variable.

It seems not to be generally known that even the Fizeau fringes for equal thickness principally can also be used in investigations of the structure of spectrum lines. These fringes are located in the wedge-shaped layer itself and correspond to a constant angle of incidence $i = 0$, while the thickness d is variable.

It may be supposed that these two extreme cases of all possible interference phenomena under ideal conditions are identical with respect to the breadth of the fringes and, consequently, also to the resolving power. The correctness of this assumption depends on the applicability of the Airy formula in both cases.

One may, however, be convinced of the correctness of these considerations after observing the Fizeau fringes at greater thickness of the air interspace, using light from a spectrum line of a known hyperfine structure. Fig. 4 shows an exposure of two fringes of the *HgI*-line 5461 A.U., taken with a distance ring, 5 mm. thick. All the familiar components of this line could easily be seen, except for the components of the central line, which were not sufficiently separated by the light source (a low pressure mercury arc lamp run with 1 Amp.). Fig. 5 exhibits a similar photograph taken with the green *TlI*-line 5351 A.U. in two orders with a 5 mm. ring. The source was an Osram Thallium lamp run with 0.6 Amp. The clear separation of the narrow components indicates that the resolving power is in the neighbourhood of half a million.

This manner of using a Fabry-Perot étalon is rather attractive, because the spectrum lines appear really as lines and not as circles. The determination of the intervals of a line structure by such an exposure has to be carried out in the usual manner by measuring the intervals in relation to the distance between consecutive orders, which is $\Delta\nu = \frac{1}{2d}$ cm.$^{-1}$. The method has the advantage that linear interpolation can be used, as the fringes are equally spaced, and the dispersion is constant.

A further advantage of this procedure is that the resolving power is independent of the deviations from planeness of the plates, because every surface element forms its own part of the fringe, irrespective of the other surface elements. At a given plate distance the resolving power of such a "wedge étalon" depends therefore only on the reflecting power of the silver film, unlike the usual interference spectroscope applying Haidinger rings, for which both the planeness of the surfaces and the accuracy of the adjustment to parallelism greatly influence the resolving power. For a wedge étalon the resolving power is then fundamentally greater than for a parallel plate étalon and is really equal to the maximum resolving power mentioned above. Only with very good plates and an ideal adjustment may the parallel plate étalon give a resolving power approaching that of a wedge étalon.

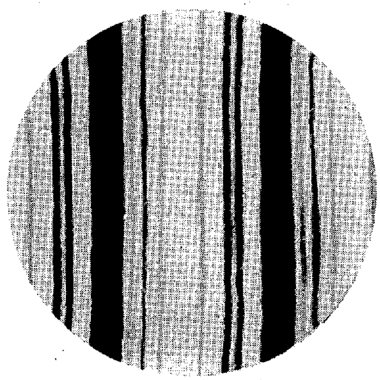

Fig. 4. Hyperfine structure of Hg 5461. 5 mm. wedge étalon.

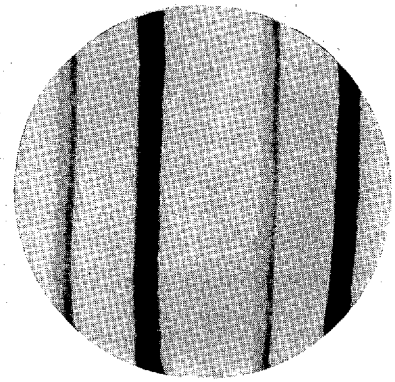

Fig. 5. Hyperfine structure of Tl 5351. 5 mm. wedge étalon.

Unfortunately, the wedge étalon can only be used as interference spectroscope in very few cases, because the intensity is too small. The advantages of the wedge étalon only appear when the fringes are pure Fizeau fringes, *i. e.*, when the angle of incidence is really constant. Consequently, the hole in the collimator must be very small, especially at thicker air layers, and therefore the interference fringes become rather faint. In fact, the photographs (Figs. 4 and 5) were exposed for $^1/_2$—1 hour, while for the photographing of the Haidinger rings with the same light sources an exposure of $^1/_4$—$^1/_2$ minute was sufficient. Owing to their weakness the Fizeau fringes can therefore only be used in the study of fine structure, if the spectrum line is very intense.

In order to obtain good results with the wedge étalon, the adjustments of the air layer perpendicular to the beam and of the light beam to parallelism should be carried out very carefully, especially at thicker étalon rings. If the layer is not strictly perpendicular to the beam, the fringes will lose their sharpness, and if the beam is convergent or divergent instead of quite parallel, the fringes will be curved instead of being straight lines. However, when using the method of autocollimation mentioned on p. 7, these adjustments could be carried out with sufficient accuracy.

For investigations of natural line breadth of spectrum lines, the wedge étalon method has the advantage of giving straight lines which are better suited for microphotometer work than the Haidinger rings. By this method the natural line breadth of the *Cd*-line 6438 A.U. was measured for the used light source by means of a 10 mm. ring. The result was corrected for the instrument breadth which was measured at very small thickness. A value of 0.05 $cm.^{-1}$, or 0.02 A.U. was found, but this value holds only if the current in the spectral lamp does not exceed 1 Amp.

Although the application of the wedge étalon to investigations of hyperfine structure is thus in most cases impracticable for intensity reasons, it is advisable to employ the method visually for estimating the quality of the silver coating of the plates. By observation of the green *Hg*-line at an étalon thickness of 5—10 mm. one can immediately ascertain whether the silver film gives the wished resolving power, as this inspection does not depend upon the adjusting of the étalon.

The application of a wedge-shaped plate as interference spectroscope is mentioned in a paper by Gehrcke and Janicki[1], who used the interference fringes formed by a wedge-shaped glass plate with silvered surfaces illuminated under different angles of incidence. In that case, however, the fringes were located at different distances from the wedge, depending on the angle of incidence, and therefore were not pure Fizeau fringes. The advantage of using pure Fizeau fringes, as done in this work, is based on the fact that cos i better can be held constant by normal incidence where cos i varies as slowly as possible.

[1] E. Gehrcke and L. Janicki, Ann. d. Phys. **39**, 431, 1912.

Summary.

Various methods for examining the planeness of interferometer plates have been investigated, and a simple arrangement has been described for such investigations both with unsilvered and silvered plates. The different sources of error were discussed, and an accuracy of the measurements of at least 10^{-6} mm. was obtained.

The influence of deviations from planeness upon the resolving power of a Fabry-Perot étalon was examined and a method was described for the determination of the maximum resolving power for ideal plates.

It has been shown that under certain conditions Fizeau fringes could be used in spectroscopy, and that maximum resolving power could be reached independent of the plate errors.

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