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The Jena repetition of the Michelson experiment

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With 11 figures

1. Introduction

Soon after D. Miller [1]) made his sensational communication about a positive ether wind effect with the Michelson experiment, checks like that were made at other places [2]), thus also in Jena it was attempted. The objective was to succeed with sequential registrations with an optical path, which should be approximately the size of the one of Miller's, which should supply a clear decision to everyone with verifiable documents. The company Carl Zeiss made large help available in a most generous way, in particular the difficult technical construction of the rotation apparatus by the construction office "Astro" (senior engineer D. Fr. Meyer and graduate engineers Büchele as well as Köppen) who did the work. For the construction of the apparatus and the photographs themselves mechanic Mr. Ziege stood to the authority of engineer Mr. Köppen. All of them are sincerely thanked for their task.

2. Description of the apparatus

a) The carrier of the optics (Fig. 1)

For the accuracy achievable, of course, everything depends on a trouble-free mounting of the optics. Already the material question

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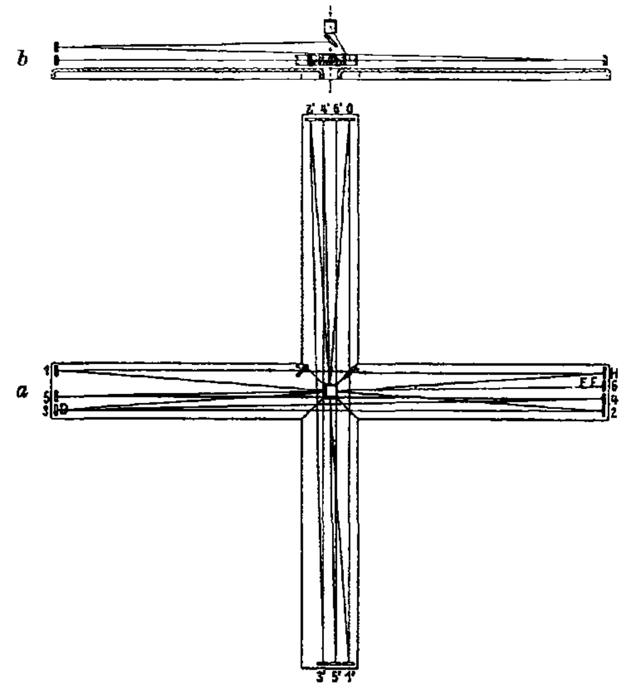
[1]) D. C. Miller, *Proc. Nat. Acad. Sci.*, **11**, p. 306, 1925; Further details of Miller in the discussion of the Michelson attempt: *Astrophys. Journ.* **68,** p. 341, 1928.

[2]) R. I. Kennedy, *Proc. Nat. Acad. Sci.*, **12**, p. 621, 1920; A. Piccard and E. Stahel, *Naturw.*, **14**, p. 935, 1926; **16**, p. 25, 1928; A. A. Michelson, F. G. Pease and F. Pearson, *Nature,* **123**, p. 88, 1929; *Journ. Opt. Soc. Amer.*, **18,** p. 181, 1929; K. K. Illingworth, *Phys. Rev.*, **30**, p. 692, 1927.

required detailed preliminary analysis, where it was explained to the authorities in the Physical Institute of the University of Jena. At first it was thought to use Invar, but an estimate calculation showed that the Magnetostriction can cause effects of the scale already expected, namely likewise with double period in the earth field. The most suitable material would naturally have been quartz glass, which was not applicable, however, with the planned dimensions of the apparatus (arm lengths of 2 m!). Now recently the company Schott and Gen has a procedure of forge pressing quartz in nearly any big size dimension. Despite the opacity that shows the material is not homogeneous, but contains many small air inclusions, its thermal expansion coefficient, compared to clear quartz glass, is not substantially different. For our purposes it depended, above all, however, to know whether the material "works", i.e. whether spontaneous small length variations arise. For this purpose, two 1m long plates were posed next to each other and interferometrically checked for any relative length variations. It resulted that in the times which are applicable for a revolution of the apparatus (some minutes to 1 hour), no length variations occurred in the least. (Whether, however, in the course of years no changes occur, was not examined!).

From this material, now the company Schott made a larger number of plates, for which I particularly owe the leader of the forge pressing department, deepest gratitude. The form selected was the one on one side at 45° exaggerated rectangle of the size 193 x 41 cm. From four such plates a cross (Fig. 1) could be built up. The plates have a thickness of 2 cm and are provided for reinforcement with a bent edge of 8 cm height (see Fig. 1b). The composition took place via that the sides were sanded off cleanly to the 45° finishes and one pressed on the other with each span by two strong clamping screws. One refrained from using a plastic intermediate layer, since it showed lasting length variations in the case of stronger clamping. In the center of the so originating cross a square an opening of 10-cm per side remained a suitable design which

served for the pathway of the rays. The plates received drillings, which could be implemented without the danger of jumping into the places

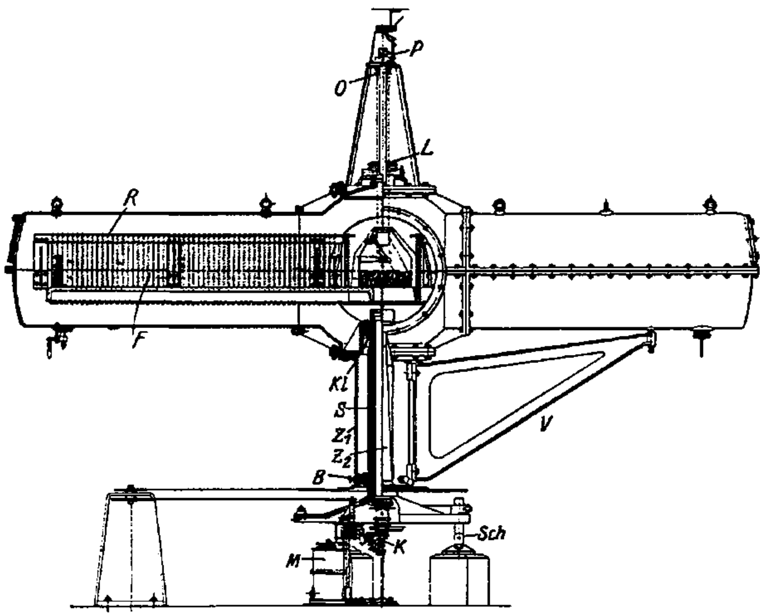


The path of rays
Fig. 1

intended for the mirrors and glass plates.

b) The rotation apparatus (Fig. 2)

If an adequate installation of the optics was thus created, there came a second question: a vibrationless swiveling storage of this cross. This question was solved in a way which deviated from the present constructions completely. Instead of letting, as before, the optics carrier float on mercury, we hung the quartz cross to a very large number of springs F hung up to the framework R where the springs are fastened onto transverse carrying bars, on which the cross rests. Each individual load of the cross, such as mirrors among other things, for the avoidance of deformations, have auxiliary springs attached to the division plate, which is attached at transverse bars lying there at the place of the load. The frame is the moving part of the apparatus. This consists mainly of a spherical centerpiece with four horizontal attachment pipes and two



Cut through the total apparatus
Fig.2

vertical downward going, concentric cylinders. The horizontal attachment pipes enclose the cross hermetically. To dampen the oscillations of the hung up cross, brushes from soft hair are attached at all four ends at the lower surface, with identical ones fastened to the tube sheets adjustably faces. The absorption can be strengthened by an advance of these brushes. In the case of strong absorption, the approach disturbances fade away very fast, on the other hand, one can also again transfer vibrations, so with the final photographs the absorption was

switched off completely. The ball and attachment pipes were poured out of Lautal metal (an aluminum alloy). For the assembly, the ball and attachment pipes had to be made of two halves with horizontal separation surfaces, which can be pressed together to form a hermetic seal. (The possibility of the evacuation was left open from the start if the disturbances became too big from the enclosed air. No use was done meanwhile of it, because these disturbances can be reduced to a minimum, while, on the other hand, a complete gas freedom - untightness by which some air continuously penetrates would of course interfere highly – since it is very hard to achieve.) The outside vertical cylinder Z_1 carries the driving pulley and four the horizontal arms carrying reinforcements *V*. The moving part of the apparatus runs on a ball bearing *Kl*, that is mounted on the upper end of the firm hollow column *S*. The foot of this hollow column can be adjusted by adjusting screws resting on three concrete bases *Sch*. Inside the firm hollow column, the second cylinder Z_2 that is connected firmly with the mobile part runs the camera *K* and carries a small slit. The adjustment of the axis of rotation had been tried at first in the way that between the firm column and the outside cylinder Z_1 were attached in the distance from approximately 1 m, two ball bearings to do the guidance. This construction showed an easy course, it had however the disadvantage that in reality two not completely coinciding axes of rotation were present, once the perpendicular to the level of the bearing seat *Kl*, other time the connecting line of the centers of the two guide bearings. Inevitable inaccuracies let the direction of the axis controllable by the behavior of an attached bubble level L, thereby only fixed to about 20". Since this accuracy proved to be too low, the two guide bearings were removed completely and turned instead of it to the firm column a ball, on which four adjustable, parts of a spherical surface sharpened representing chuck *B*. The bearing seat was then trained in such a way that it at the same time takes over the lateral guidance at the upper end. It can be achieved by the adjustment of the jaws that the axis of rotation deviates by less than 1" from the vertical. This advantage cancels the disadvantage of a somewhat heavier gear. The drive takes place via an electric motor *M* coupled with an astatic Zeiss modulator Model 111 after Meyer by means of a cord belt transmission. This drive proved to be a better transfer in experiments, such as with a screw drive, as regards to the freedom of shock about it. The translations were selected so that a revolution of the apparatus occurs in 10 minutes.

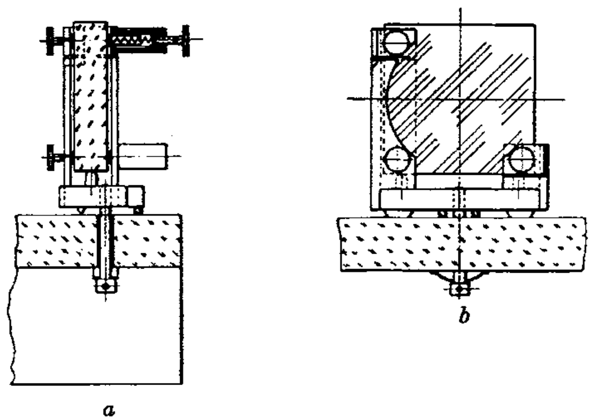
c) The path of rays (Figs. l and 2)

In the first series of tests, a quartz-glass mercury lamp with a Monochromatic filter for 5461 Å was set up as the light source outside of the test section and the light beams entering by a horizontal opening in the test section and projected by means of a mirror into the direction of the axis. During this arrangement however a puzzling feature showed up: a simple periodic walking of the interference fringe image *including the zero-marks*. Since within our arrangement the zero-marks are at the place of the interference (see below), no fallacies should originate from this feature. The explanation is rather surprising: The illustration of the interference fringes takes place (see below and Fig. la) through the two glass plates that are adjusted 45° into the path of rays. If now by unsatisfactory centering of the beam of light during a rotation, these plates are implemented by somewhat differently inclined beams, a shift of the image must occur. Since it was shown that a sufficiently exact adjustment of the entering beam was hard to achieve (with each startup it was somewhat changed, yes in the direction and for apparatus axis, and central beam was allowed to deviate about 10" from each other!), the disadvantage of heat development was taken in the observation area by the purchase of the source of light, a Heraeus point mercury small lamp *P* (Fig. 2) by only 25 Watts power absorption attached on a rack high over the apparatus and co-rotates calmly. The electric current feed takes place from the cover with two slip-rings. First the light withdrawing horizontal from it is thrown by a total-reflecting prism in the direction of the axis. The light is made parallel in the distance of the focal length of the source of light and the distant objective lens *O*. The monochromatic filter is also on the objective. Over the center of the quartz cross, 45° mirrors throw the light first to the end of the arm to a further sitting plane mirror, O (see Fig. 1a). From here it arrives at the division plate. Each of the two partial beams is thrown now three times in the level of the cross back and forth. There in such a way developing the length of the two optical paths arriving at the interference amounting to 20.99 m. After the reunion of both beams the light meets the concave mirror illustrating the interferences which throws the beam at first on a little bit higher situated mirror at the opposite end of the cross and from there onto one in the middle and to the right, via a 45 ° inclined plane mirror. This brings the rays in the axis of the apparatus down to the camera. Before that mirror, because of its place the interference are - which is that to the beams going through by the subpanel in itself are thrown back - three thin wires in a mount are inquiring for the production of zero-marks. It proved as necessary to attach several zero-marks since very often a mark lies so unfavorably to the interference fringes that the dimensional precision became insufficient. On the other hand also every now and then a fringe measurement became useless because of the maximum size of a mark.

The marking of a certain position of the apparatus takes place via a narrow metal strip, fastened to the cover of the test section, which covers the path of rays briefly during the rotation once behind the small point lamp. The electromagnetically-movable mirror on the basic arm forms in this position with the north direction an angle of 20° to the west. On in Fig. 9, one sees in the reproduced photographs the appearance of vertical marks that do not stand exactly perpendicular to the interference fringes. This possibly does not come along that the fringes did not lie quite vertically to the gap right at the picture place. Rather, the cause lies that the metal strip extinguishes first one-half of the strongly diverging beam, which corresponds to one disk half, and then the extinction of the other half when the plate has advanced a bit.

d) Details of the optics (Figs. 3 and 4)

The mirrors are square surface-silvered glass plates of the size of 7 x 7 cm, the half-silvered division and the compensating plates have a size of 7 x 11 cm.



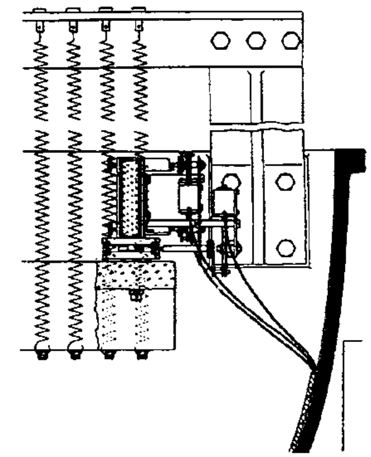
Installing the mirrors
Fig.3

For the avoidance of surplus reflections, these two plates are somewhat wedge-shaped polished and in such a way set up that they work together again as level plate. The assembly of the mirrors is shown in Fig. 3. Coarse adjustment is effected via three simple screws; the micro-adjustment by change of the spring tension in the back support is enabled by three more screws. The holders are fastened for their part by a screw on the quartz plates and two edges and a ball serve as a support.[1])

It was shown that with manual adjustment of the mirrors through one of the lockable hand holes led in into the tube sheets by plates such thermal disturbances developed, that it took hours, until the interference

[1]) In Fig. 3b reproduced design indicates 2 balls; that changed during the execution however.

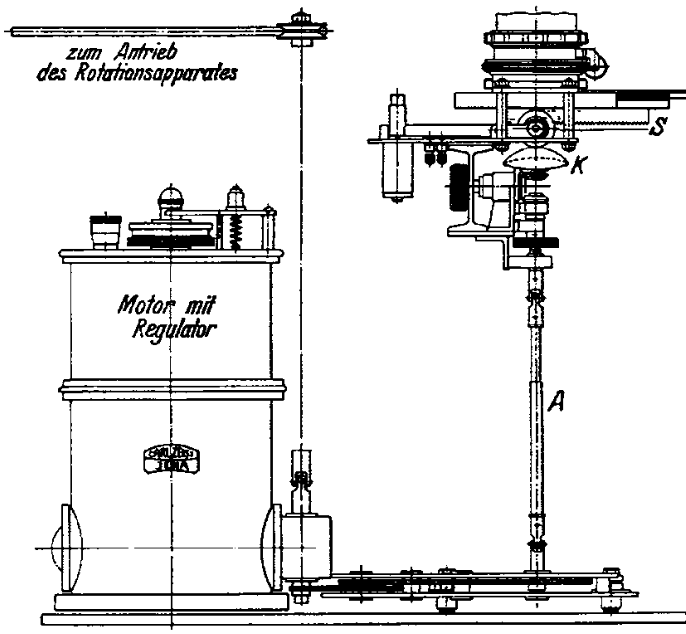
fringes had again calmed down, whereby the position was not at all always the desired. For this reason and for adjustment with evacuated apparatus an electromagnetic fine movement was appropriate at a mirror (Fig.4). Three set screws - one for a translation of the whole mirror, two for the inclination - are ever connected with two gear wheels, which are moved forward or backward with the use of gear teeth connected to electromagnets. Attached to the wall of the test section there was attached an instrument panel with six contact buttons for these three screws - one for forward motion, and one for backward motion - are installed next to observation eyepiece serving a telescope. The lines are led inside the apparatus to a plug contact sitting in the tube sheet, into which the adjustment lines coming from the contacts are put. After the adjustment these cables must be naturally be removed again for the rotation.



The electromagnetic
fine movement
Fig.4

e) The movie camera. (Fig.5)

At the lower end the internal drive cylinder Z_2 in Fig. 2 sits the camera, which can be brought to move the correct distance by means of a worm gear. The cartridge runs past a 0.2 mm broad gap, which cuts a small piece out of the interference pattern perpendicular to the fringes, during the slow rotation. In order to achieve each desired transport speed, the following mechanism was met: the movement of the cartridge Ks takes place via a gear wheel, which intervenes in a rack connected with the cartridge. The gear wheel sits on same axis with a grinding wheel *S*, which sharpens on an inclinable round swivel *K*, which is driven by the motor. Depending upon the zone at which the grinding wheel is mounted, a larger or smaller transport speed can be ordered. The drive axle *A* serving for the turn of the swivel consists of two telescope-like, into one



The camera and the drive
Fig. 5

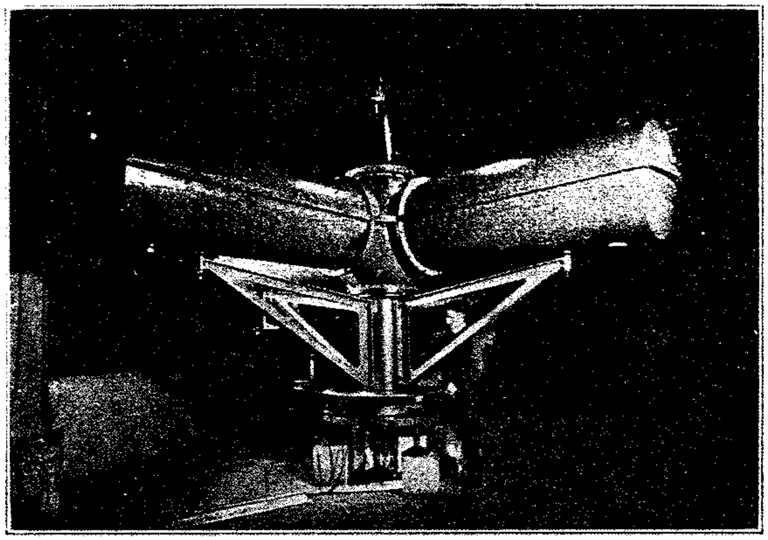
another, adjustable square tubes. This is therefore necessary, so that one can constantly vary the length of the drive axle during the focusing of the camera. The transmission from the driving motor takes place via a gear wheel work. For more flexible connection, the axle is fastened to both the drive wheel and the swivel with a universal joint. The used disk format is 3 x 12 cm. For eyepiece observation, a prism can be inserted into the cartridge, which enables an observation of the whole interference

pattern; after distance of the slit diaphragm a laterally set-up telescope is made possible. Naturally this goes only in a certain position of the apparatus; during the rotation an eyepiece for observation is not possible.

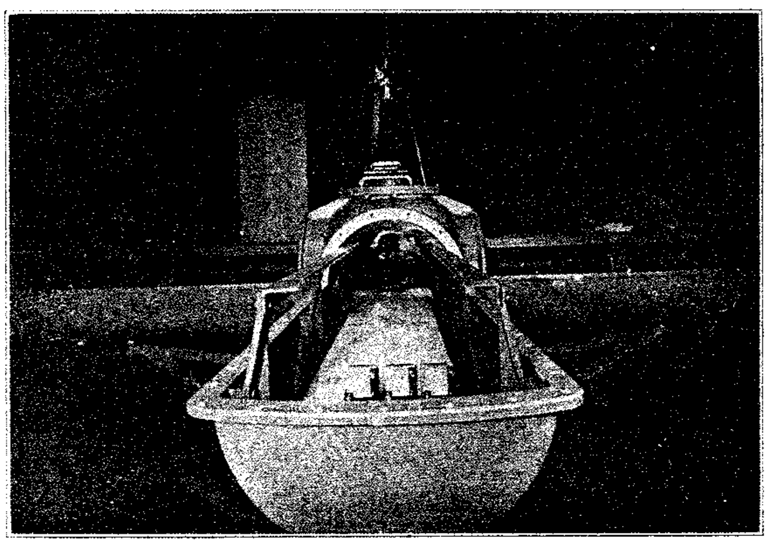
3. Installing and adjustment of the apparatus

In a cellar area of the Zeiss work, the equipment was developed. First the lower parts of the rotation apparatus were built up and the lower halves of the pipes with the frameworks carrying the cross were screwed on. Then the quartz cross was built up first at a pulley-block above the apparatus floating and finally lowered into its springy storage, on which the attachment of the mirrors took place. The raw compensation of the optical paths took place by means of precision yardsticks, which showed a length of the interfering rays of light of 20.99 m.

The mutual inclination of the mirrors was first adjusted thereby that by an aperture at the place of the division plate a fine beam was faded out and this was always steered onto the respective mirror center. A finer adjustment was reached then still by that the observation telescope which was adjusted to the pictures of a needle held before the division plate and these were brought into focus. After putting the covers on, one could already recognize interference in the telescope. The more exact calibration of the optical paths took place then by means of the colors appearing in the unfiltered Hg-light. An equality exact on light wave length is not necessary by this way. The last positioning took place with completely closed apparatus by means of the electromagnetic fine movement of the mirror. The main difficulty was to adjust the fringes on longer time perpendicularly to the camera gap since naturally only then by the movement of the plate a pulled apart picture of the interference fringes with any periodic shifts can come. It was shown that it was best to give the curves of same thickness to the producing wedge a horizontal edge because then a change of the temperature stratification of the enclosed air could only cause walking, not however a much more



Complete view of the interferometers
Fig. 6

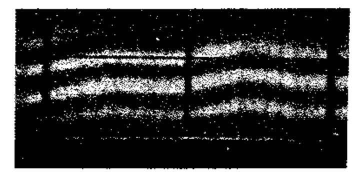


The storage of the optics
Fig. 7

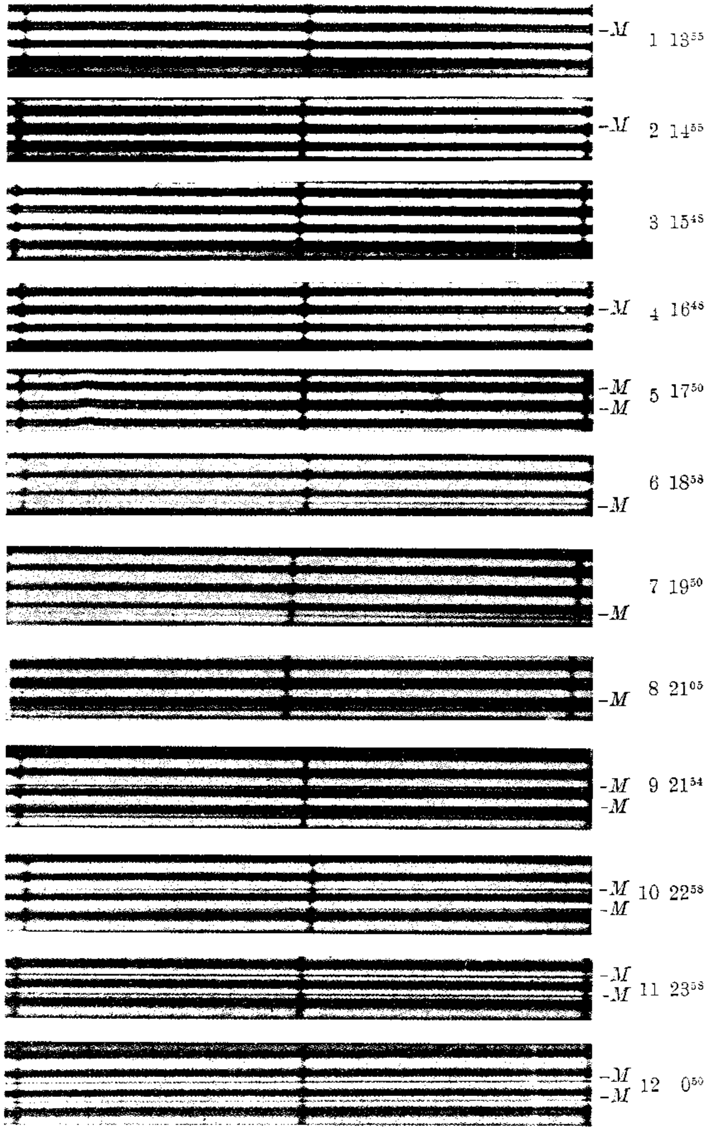
disturbing turn of the interference fringes. By means of the set screw attached at the foot and a bubble level put on the apparatus, then the axis of rotation was set exactly vertically to 1". Fig. 6 gives the complete mounted apparatus; Fig. 7 by absence of the upper pipe halves obviously shows the quartz cross with the optics.

4. Course of the photographs

Both with first execution, when the source of light was outside of test section, and then with the final, when the source of light corotated, countless photographs were made, in order to study: the influence of axle separation, the temperature and other sources of error. A suggestion of a corresponding to an ether wind effect, with which half revolution periodic shift known amount will receive only if during extreme tilt of the axle (inclination of approximately 1') the cross were periodically deformed by the mounting of the damping surfaces. Against it, verifiable fringe movement periodical with the full rotation seemed photo-metrical already with relatively small spatial differences in temperature (with some tenths degree of difference between inner wall and outer wall of the test space). As a check, whether the cause really lies in the local temperature differences, it was heated inside by an electrical furnace, whereby in Fig. 8 shows the resulting curves. After removing the furnace and temperature equalizing, the fringes became again straight. (The shaky appearance of the fringes comes along that with these photographs of saving of time because of a relatively strong absorption was adjusted by the absorption brushes, whereby rapid fading away of rough disturbances was caused, on the other hand in addition, a transmission of vibrations.) Obviously the mirror, which is provided with the electromagnetic micro-adjustment,



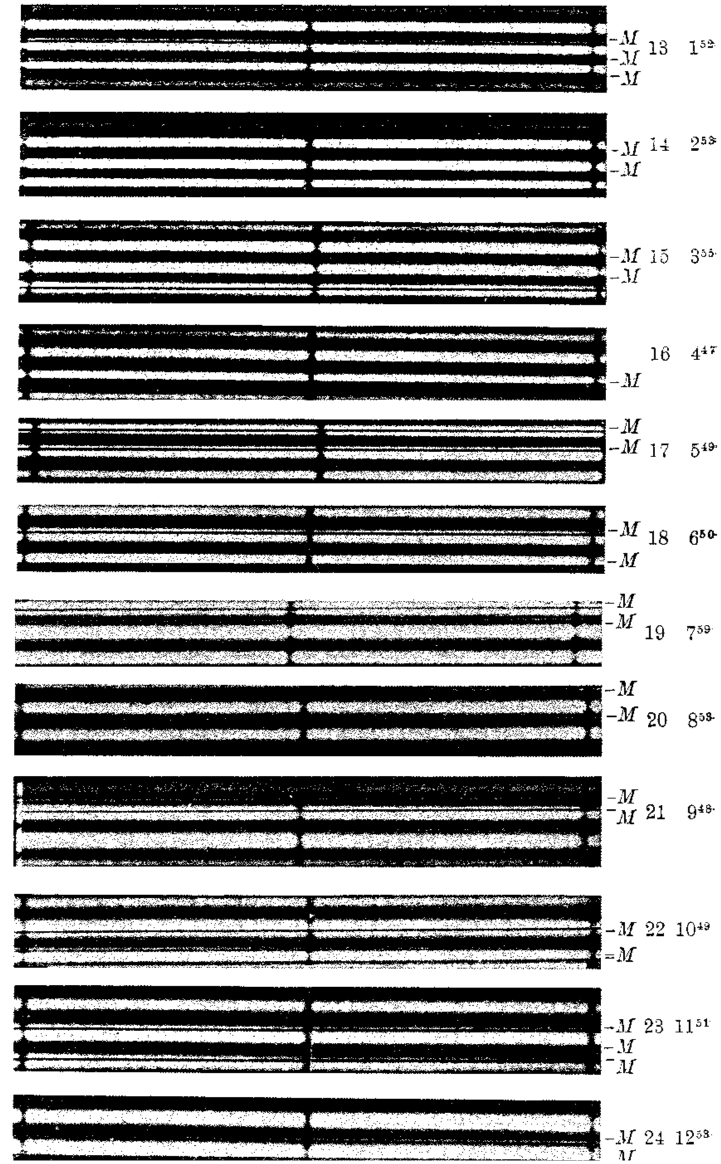
Heating produced by unilateral
Strip displacement
Fig. 8



Trials on 10 May 1930

Fig. 9a

(Since the marks extinguish the one of the interfering beams, they appear darkly bright in the places of largest brightness and in the places of smallest brightness.)



Trials on 11 May 1930

Fig.9b

responds with particular ease to changes of temperature.

After a certain control of the disturbances was reached by such controlling attempts, the final trials approached. There, when exact measurement of the registrations are made, a very small shift effect is nevertheless to be expected; actual zero is for the physicist just as an iterated point at infinity is for the mathematician - from the beginning one proceeded to receive series from photographs, over 24 hours it extends so that from the course of the fluctuations a judgment can be won whether it concerns a real ether wind effect or in the region of coincidental dispersions. With the first such series, with which photographs were taken continuously, in particular still very many small vibration disturbances occurred at the beginning each plate. The cause lay with necessary disk exchange such that after two revolutions of the apparatus vibrations arose, which had faded away but not yet completely at the beginning of the trial. (The disk exchange is actually somewhat difficult, so that small vibrations are unavoidable. The observer must slide on his back under the apparatus during the rotation, in the dark, to load the film cartridge into the camera. Disk transport is then electrically switched on.) When the photographs from 10 May 1930, arrived for evaluation, these vibrations were avoided thereby that at one revolution duration by 10 minutes in one hour only 2 registrations were made on a plate. After the disk exchange a half hour was waited and the disk transport was electrically switched on by an observer outside of the test section. The rotation of the apparatus was naturally not interrupted. It ran dry rather to the temperature equalizing at the beginning of the photographs already two days long. The outside vibrations were reduced thereby that the trial day was put on the time from Saturday noon to Sunday noon, thus on the time of the work it was peaceful. The conditions of temperature were likewise best attainable. The difference between interior and external wall at the beginning of the attempts was less than $^{1}/_{10}$°. Also the

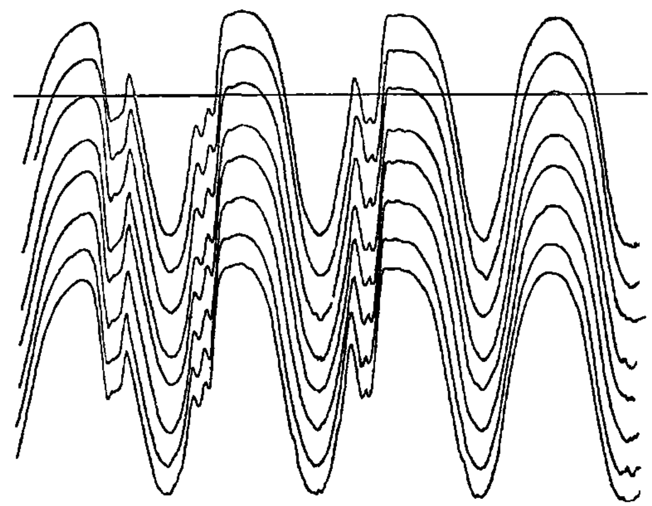
absolute value of the temperature, on which it does not depend however so much, remained constant on few tenths degrees (means 15.5° C) Only in the course of the night were there differences of several degrees, due to cooling of the external wall and heating by the source of light up of the area arose to tenths. They are the cause for gradual movement of the fringes. In Fig. 9 is shown copies of the original plates. The first trial still shows a certain restlessness of the fringes, because the disturbances resulting from startup were not completely compensated for. At the 5th trial is contained a rough disturbance, which was caused by slamming a door shut in the works. After all, the apparatus responds to acoustic disturbances relatively strongly: If one applauds in the test section with the hands, then one receives clear seriating in the registration curves. Since in addition this plate 5 exhibits some places with friction veil, it was excluded from the evaluation.

5. Evaluation of the plates

With the eye, a trace showing a periodic shift is to be recognized on none of the photographs. In order to be able to indicate however the limit for a still possible effect, a rather complicated evaluation procedure was used: The distance, which corresponds to a revolution and which was 4 cm long in the final photographs, were divided into eight equal parts and each of these parts was analyzed with a Zeiss registering micro photometer by G. Hansen for perpendicularly to the transport direction by photometrics. There during 24 hours, 48 revolutions of the apparatus for the trial, meaning for this trial a series of 384 registrations. During the past constructions of the registration photometers the shade of the electrometer thread is brought to the illustration and exposed thus when unique going through the whole registration plate up to the curve, which describes the silhouette. Thus tremendous disk consumption is not to be avoided in our case. In the newest construction of the Zeiss photometer can however also with dark field lighting of the electrometer thread to be worked. With a small adjustment of the optics, multiple registrations can be made on the same plate. Figure 10 shows the registration of the first half of plate 9: all 8 registration curves belonging to one revolution on a plate place. One sees the sinusoidal density curves with the prongs of the three zero-marks. Whichever is the distance of the maxima and minima from the zero-marks is not like one would think at the sight of the figure from perpendicular. It could not be begun with moving the plate which can be registered *exactly* in the same place with photometry, so that has to mean approximately vertical to lie on top of each other of the corresponding places, nothing more, that by it a clear separation of the individual curves is reached.

The in such a way, received registration plates were measured first by an auxiliary worker, for whose grant I would like to thank the Emergency Association of German Science in the best way. The series from 10 May 1930, which contains 80 well like no disturbances, became from the author again on more details checked, whereby the differences between both measurements showed maximally $^{5}/_{1000}$ fringe widths (the previous photographs contained, for reasons discussed above in detail, too much vibration disturbances, that they could be judged equivalent). Measuring took place in the way that the plates were put on graph paper and studied in translucent light. The horizontal straight line produced by elimination of the lighting of the photometer in Fig. 10 served as the straight layout. Now for each extreme the situation was intended thereby that about 3 mm was read off exactly above and/or below the extreme from two to three places the intersections of the curves with horizontal straight lines on tenth millimeter and the means from these two reading off was taken. Naturally only such extreme could be consulted for the measurement, with which the symmetrical process is not disturbed by a zero mark prong lying in the proximity. In the majority of all plates, however, three to four extreme for measurement could be used. In the

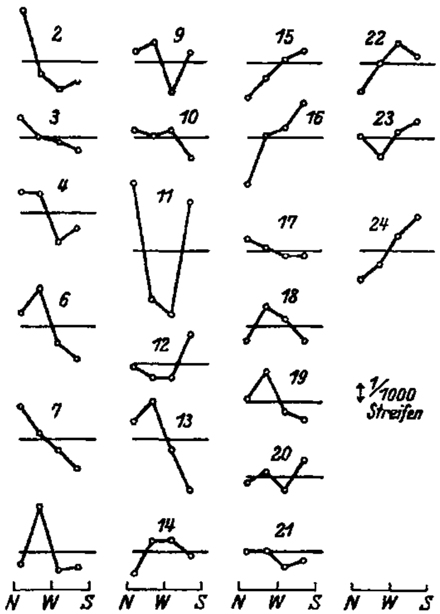
same way the exact situation of the zero-marks was determined. For each registration the difference of the average value of the extreme and the average value of the marks in thousandth of a fringe was measured last. In the case of the photographs 1-10, completely irregular fluctuations result around the average value. Some of the 11th recording is a clear continuous course of about $^{1}/_{100}$ fringes per revolution to recognize the deterioration of the conditions of temperature effect.



Registration curves of the interference fringes of plate 9
Fig. 10

This course can be corrected relatively easily, however: it was the difference between two successive positions of the same apparatus and determines the eighth part of the difference of each curve was added each time from registration curve to registration curve. *An influence on the periodic portion of the fringe shift does not take place naturally via this course correction.* Also suggestions by a full-periodic fringe shift were to be recognized with these later photographs. Their elimination takes place via that the means from 1. and 5., 2. and 6., 3. and 7., to which 4th and

8th section is taken, whereby appropriate half-periodic shifts remain again uninfluenced for the ether wind effect. Besides, it was still the average from the two revolutions, which are contained on a plate that was taken. With the trials, only 1 of the first revolutions had to be omitted because of the irregular disturbances. Likewise trial 5 falls completely out (see above). The final result is shown in Fig. 11. If we take these curves as genuine ether wind effects, then the deviation zero means that the electromagnetically moved mirror basic arm stands at 45° and/or 135° for the direction of the ground distance of the ether wind. A maximum means that this arm is *in* this direction, a minimum that stands perpendicular to it. (The sign is not to be decided naturally because of the value-squared nature of the effect.)



Strip shifts with the turn of the apparatus. (The written down directions refer to the direction of the emphasized arm)
Fig. 11

One could remember now to determine by Fourier analysis the dominant mode of these curves and thus amplitude and direction of the "ether wind". This procedure does not, however, make much sense for the following reason: If a repetitive component of the shift is present by unsatisfactory course correction, then also this, which has surely nothing to do with the ether wind, contributes to the dominant mode, because the Fourier analysis has a periodic repetition of this course and not an even continuation for the condition. That means that depending upon the more

or less fluke correction of the course for the amplitude and phase, anyone can receive a dominant mode. It is more appropriate to form by detailed view of the curves a judgment over the reality and the lower limit of a possible ether wind effect. First the large amplitude of the trial 11 explains itself thereby that the zero-marks lay here so unfavorably that no maximum of the density could be used for the measurement, while the nearly crystal clear minima showed rather shaky registration curves from a light lime haze of the plate. Which of course is to be expected now with a real ether wind effect? Since the point of the celestial sphere from which the ether wind comes from, in the course of a day like a star comes up and goes down, but with the Michelson experiment, where only the horizontal component of the ether wind is being measured, the following cases are possible: a) the ether wind comes from the Poles. In this case, the direction and size remains constant, the curves would then fail all the same with their maximum deflections in the meridian position; b) the ether wind point is located near the celestial equator, it would be a periodic change of amplitude and direction of the result, with the direction of all angles from 0 to 360° and passes through a minimum of strength in the culmination or anti-culmination would occur. Would have thus on the photographs, with which the maximum deviations arise with the meridian position of the emphasized arm, which run even flattest curves. This is valid also for the intermediate case that the point of ether wind has a middle declination, whereby the azimuth of the direction, and oscillates between two limits. One cannot with the best will in Fig. 11 show curves arranged under one of these cases. The periodic portions must be substantially smaller thus than the fluctuations found here. After the yardstick of the figure however a periodic portion of $^1/_{1000}$ fringe would have been still well perceptible. *We can indicate thus with good conscience that the upper limit for a real ether wind effect still possible due to these attempts at $^1/_{1000}$ fringe.* Thus the information of Miller, after who in the low country with a 1.5 times larger optical path observe shifts up to $^1/_{10}$ width, might be attributed to disturbing influences. To make a comparison, for the accuracy sought, if one sets $^1/_{1000}$ fringe as upper limit, the following can be said: with an optical path of 21 m and a wavelength of 5461 Å, it means that a change of $^1/_{1000}\ \lambda$ equals a relative change of $2.6{\cdot}10^{-11}$. Let the distance between the earth and moon be around $3.6{\cdot}10^{10}$ cm, this corresponds to relative accuracy of the claim that a change of this distance to 1 cm should still be detectable. This is also one where Strömberg [1]) calculated the effect of $^{17}/_{1000}$ fringe widths shift for 16 m, which Michelson said, will certainly not exist as proved.

Less obvious is the progress in accuracy, if you strip out the displacement *against the central position* after the well-known formula

$$(1) \qquad \Delta Z = \frac{l}{\lambda}\left(\frac{v}{c}\right)^2$$

the limit of the speed of v of the ether wind is calculated. Because of square of v entering, a $^1/_{1000}$ fringe accuracy causes as upper limit for v to be 1.5 kilometers/second.

To draw a comparison with an "expected" effect is rather pointless, since we now know that most of the Earth through the joint velocity of the Milky Way system (magnitude 300 km/sec) is given, though the direction and amount has significant uncertainties. The full effect of this movement would cause a shift of approximately 38 fringes, which one can see immediately by using Equation (1).

It was originally planned that the apparatus would be constructed at the Jungfrau Yoke. Mr. Lichti director of the Jungfrau Railway Society supported the preparation warmly, for which we were extremely grateful. Meanwhile, however, by the withdrawal of the originally specified height dependence of the effect of D. C. Miller, the situation changed

[1]) Mentioned in the work of Michelson, Pease and Pearson, quoted above. Details could not be gotten to know about it.

significantly and it is fair to ask, whether, given this change, also in view of the failure of all repetitions undertaken and the completely negative Trouton-Noble experiment [1]) and given the financial plight of the German research would the cost of such an expedition be justified.

Summary

A registering Michelson interferometer is described by 21 m optical path. Micro-photometric measuring of the photographs taken thereby shows that an existing ether wind effect would have to be smaller than $^1/_{1000}$ fringe width, the amount of the ether wind smaller than 1.5 kilometers/second.

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[1]) R. Tomaschek, *Ann. d. Phys.*, **78,** p. 743, 1925; **80**, p. 509, 1926; **84**, p .161, 1927. C. T. Chase, *Phys. Rev.*, **80**, p. 516, 1927.

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