ON A NEW FORM OF INTERFEROMETER.[1]

By CH. FABRY and A. PEROT.

IN a series of memoirs[2] published by us during the last three years we have described various applications of fringes produced by silvered plates. The special properties of these fringes will, in our opinion, render possible a notable extension of the already wide field comprising the applications of interference fringes. The applications which we have already described relate to the optical measurement of lengths, to the comparison of wave-lengths, and to spectroscopy.

All of these experiments have been made with apparatus which we have constructed with no aid from the instrument-maker other than that required in preparing plane glass surfaces. These are the instruments, ordinarily of very simple construction, which we have described in the memoirs already referred to. These instruments, improvised for the occasion in order to avoid serious loss of time, necessarily contain various imperfections. We have always taken care to conduct our experiments in such a way as to avoid the influence of these imperfections on the accuracy of the results. A characteristic feature of our methods is that the observer has constantly before his eyes, in the very appearance of the phenomenon under observation, a proof that the adjustments are rigorously exact. But imperfections of the apparatus nevertheless make the preliminary steps in

[1] Translated from an advance proof from *Annales de Chimie et de Physique*, communicated, with additions and illustrations, by the authors.

[2] "Sur les franges des lames minces argentées et leur application à la mesure des petites épaisseurs d'air." (*Ann. de Chim. et de Phys.*, 7e série, t. XII, p. 459; 1897.) "Théorie et applications d'une nouvelle méthode de spectroscopie interférentielle." (*Ibid.*, 7e série, t. XVI, p. 115; 1899.) "Méthodes interférentielles pour la mesure des grandes épaisseurs et la comparaison des longueurs d'ondes." (*Ibid.*, 7e série, t. XVI, p. 289; 1899.) "Sur les sources de lumière monochromatique." (*Journ. de Phys.*, 3e série, t. IX, p. 369; 1900.) "Électromètre absolu pour petites différences de potentiel." (*Ann. de Chim. et de Phys.*, 7e série t. XIII, p. 404; 1898.) "Mesure du coefficient de viscosité de l'air." (*Ibid.*, 7e série, t. XIII, p. 275; 1898.)

A brief résumé of these investigations was published in the ASTROPHYSICAL JOURNAL, Vol. IX, p. 87, February 1899.

every investigation much more troublesome, and may even render impracticable an application which would be easily effected with a more perfect instrument.

These considerations have led us to order from M. Jobin an interferometer suitable for the convenient observation of the phenomena of silvered plates, and consequently for the realization of the various applications described in our papers. This apparatus, which has been constructed in a most perfect manner, is described in the present article.

The greater part of our applications of the interference phenomena of silvered films depend upon interference at great difference of path, produced by transmission through two plane surfaces, rigorously parallel, with transparent silver surface; the interference rings are observed by means of a telescope focused for parallel rays. These conditions determine the essential parts of the interferometer with silvered plates; they consist simply of two plane surfaces, provided with all necessary means of adjustment for orientation and displacement. It must be possible to adjust their relative orientation and particularly to render them rigorously parallel. Their distance must be susceptible of varying from contact up to 10 cm; it is very convenient to have this displacement effected by an exactly parallel motion in such a way as to preserve the parallelism of the surfaces. It must be possible, during this parallel displacement, to stop at any desired distance within a few thousandths of a micron, but displacements of several centimeters must not require too much time. This leads to the use of three different rates of adjustment: (1) rapid motion; (2) motion slow enough to permit the fringes to be counted; (3) displacement by flexure through a range of a few microns, as slow and as delicate as may be desired.

Similarly, there are two distinct adjustments for orientation: a quick motion of great amplitude for approximate adjustment, and a very slow motion of orientation of small range, produced by flexure.

The adjustments by flexure are all obtained by the pressure on pieces of steel of small rubber bags filled with water and connected by means of a long rubber tube to a funnel containing water whose height can be varied; by changing the height a variable force is applied by means of the bag upon the piece of steel against which it presses. This arrangement has the following advantages: the bag being wider than the metallic piece against which it presses, the tension of the rubber does not enter

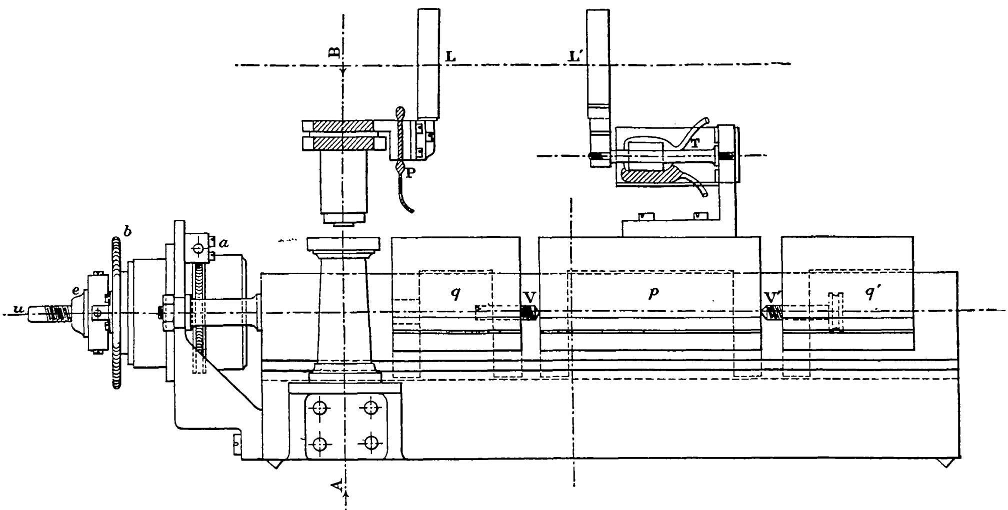

FIG. 1.

and the force depends only upon the pressure exercised by water; as this is defined by the height of the funnel, there need be no fear of a change in the adjustment from this cause during the progress of the work. Moreover, the pressure may be varied as slowly as is desired, and with this arrangement absolutely perfect adjustments are obtained; it may be added that the pressures are produced without giving any shock to the system, which is indispensable in order to avoid any disarrangement.

These are the essential elements of the instrument. Let us now proceed to the detailed description.

L, *L'* (Fig. 1) are the two plate-carriers in which the silvered plates are supported; each of these is a disk 40 mm in diameter with projecting shoulder, by means of which it can be fastened in the plate-carrier without danger of distortion. The silvered face is rigorously plane, the reverse only approximately so. The two faces are not parallel, but make with each other an angle of about 1′, to prevent interference in a single plate, which would interfere with the phenomenon under observation.

The plate-carriers have the following adjustments: *L*, toward the observer (Fig. 2), may be given quick motions for orientation and very small parallel displacements. The first of these motions is obtained by rotation about two axes, one of them vertical, *O*, the other horizontal, *O′*, as in a theodolite. The small parallel displacement is produced by bending a strong steel spring *P* (Figs. 1 and 2), attached at its middle point to the theodolite axis *O* on one side, and to the plate-carrier on the other; this spring consists of two steel bars 16 cm long by 2 cm wide and 4 mm thick, connected at their two extremities *E* and *E′* by means of metal plates. The rubber bag used to produce the displacement is shown in position in the cuts. A change of 1 cm in the height of the funnel produces a parallel displacement of 0.15 μ. The total range employed has never exceeded 20 μ.

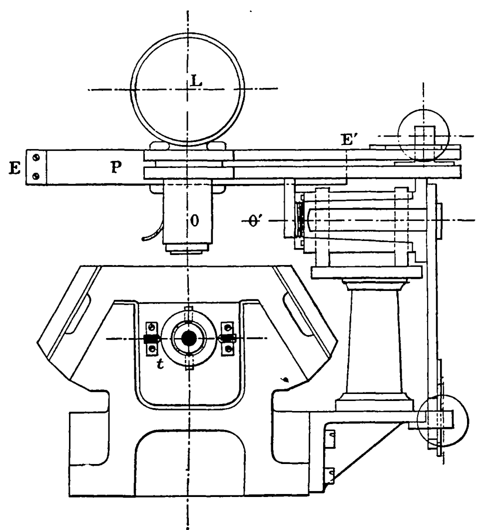

FIG. 2.

The plate-carrier *L′* (Fig. 1) may be given fine adjustments for parallelism and large parallel displacements, either rapid or slow. *L′* is carried at the extremity of a steel shaft *T* rigidly held at the other end, on which is fitted a bronze block, against which two rubber bags press in two directions at right angles to each other. A displacement of one centimeter of each of the corresponding funnels produces an angular displacement of 0″.25.

To obtain perfect parallelism it is frequently necessary to adjust the height of the funnels within a millimeter.

Finally, large parallel displacements are obtained by means of a bronze carriage on guides, p (Fig. 1), the bearing surfaces of which are worked with great accuracy. The displacement of the carriage is not produced by operating directly upon it; for this purpose it is placed between two shorter carriages, q, q', rigidly fixed with respect to each other; it may be moved by these in either direction by means of butting screws V, V', bearing on suitable points, which allow a little play. p is thus always free on the guides, where it rests by its own weight, and is acted upon when in motion only by forces parallel to the displacement, which produce no tendency to rock; it is doubtless on account of this device that it is possible to follow the fringes even when the carriage is moving. The two carriages q, q', are connected to a screw u whose head t (Fig. 2) is attached by a Cardan suspension, of which the nut e (Fig. 1), susceptible of rotation only, is also carried by a Cardan suspension. Lateral strains due to imperfect centering are thus avoided. There can thus be transmitted to the principal carriage only such impulses as are exactly longitudinal. The nut e can be moved rapidly by a milled head b or slowly by a tangent screw a. In the latter case one turn of the screw corresponds to about 15 fringes; it is possible to count the fringes.

It is very convenient to be able to quickly determine at any time the distance between the two silvered surfaces within a few microns; a scale divided to fifths of a millmeter is provided for this purpose, attached to the carriage p, and read by a microscope with micrometer eyepiece fastened to the bed of the apparatus. One division of the head equals 1 μ. The zero is determined by setting the two surfaces at a known and easily calibrated distance; for example, that which corresponds to the first resolution of the two yellow lines of mercury (40μ).

Finally, to prevent vibrations the apparatus is carried on a small table hanging by four rubber cords, whose points of support are adjustable so as to permit the apparatus to be leveled.

A solid body[1] whose dimensions are to be determined is suspended between the interferometer plates in such a way that its

[1] *Ann. de Chim. et de Phys.*, 7 ser., **16**, 289.

faces can be made parallel to those of the silvered glass planes. The form of the support depends upon the dimensions of the solid body; it is always such as to permit displacements in distance or in inclination. In certain cases, such as the measurement of the quartz cube employed in the determination of the kilogram, perfect parallelism could be obtained through flexure produced by the rubber bags. The apparatus itself does not include this support and it is not represented in the figures.

Such, in general, is the new interferometer constructed by M. Jobin; it will be seen that it is especially adapted for the observation of interference fringes at great difference of path and for the applications of these phenomena. It is evident that it may also be employed to produce the phenomena of thin plates in parallel light; it is only necessary to put the plates a short distance apart and to give them the desired angle by means of the corresponding adjustments; the distance can then be varied without changing this angle.

It is also very easy to observe *superposition fringes* in white light, the numerous applications of which we have already indicated. If the fringes of thin plates[1] are desired the silvered surfaces of the interferometer are placed a short distance apart and upon the thin layer of air thus obtained there is projected the image of a *standard film*, which may be easily constructed by placing two surfaces of silvered glass in contact. By varying the path at a uniform rate by means of the tangent screw of the apparatus the various systems of fringes which correspond to the various simple ratios of the two thicknesses of air will be seen to appear successively. In this way at least ten systems of fringes in white light, easily distinguished from one another by their appearance, can be observed successively.

If thick layers are to be employed[2] both must have parallel surfaces which must be capable of orientation with reference to each other. One of these layers will be in the interferometer itself; the other may be a layer of air with parallel faces at a

[1] *Ann. de Chim. et de Phys.*, 7 ser., **12**, 459.

[2] *Ann. de Chim. et de Phys.*, 7 ser., **16**, 289.

fixed distance apart. We have constructed such layers and named them *standards of thickness*.[1] For experiment we have constructed in the laboratory standards of thickness varying from 0.25 cm to 12 cm. Fig. 3 represents a 1 cm standard made by M. Jobin. It consists of a steel plate A pierced by a circular opening in which are fastened three small steel screws P, the ends of which are carefully rounded and polished. Against these three curved surfaces plates of plane silvered glass L, L', are held by Brunner spring clamps, and are thus maintained at a fixed distance. By carefully scraping the steel pins the silvered plates are brought to perfect parallelism. Experience has shown that after dismounting and replacing the glass plates their parallelism is preserved and the thickness of the standard does not change.

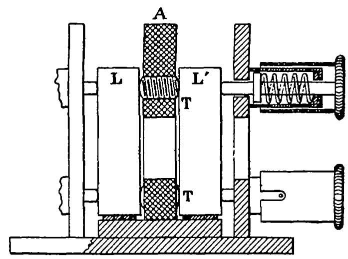

FIG. 3.

If then a convergent beam of monochromatic light is passed through the standard the phenomena of thick silvered plates will be visible. The adjustment of the standard, begun by the observation of multiple images, is completed by observation of the rings themselves. When the thickness exceeds about 20 cm the fringes in monochromatic light are no longer visible, and it becomes necessary to employ other methods which will be described later.

For the observation of superposition phenomena this plate is carried by an adjustable support standing beside the interferometer.

The use of these superposition fringes permits the interferometer surfaces to be set always at the same distance (that of the standard or one of its multiples or submultiples); this distance will be exactly known if the standard has been measured. It is thus possible to graduate the scale of the interferometer by investigating the various intervals successively and moving along the scale. Conversely, the fringes permit the measurement in wave-lengths of a constant standard, either by a direct

[1] *Comptes Rendus*, 130, 492, 1900.

determination on the interferometer or by two sets of measurements if its length is too great for the first method.

We believe that the applications of these fringes are far from being exhausted. They adapt themselves to the most varied combinations. As an example we may cite the possibility of measuring in a single operation the sum or difference of two different lengths which may or may not be capable of direct comparison, or any quantity of the form $pe+p'e'$, p and p' being small positive or negative integers. We shall have occasion to return to these various applications at some future time. In our present investigations the apparatus which M. Jobin has constructed in such perfection is proving itself to be of the greatest service.

Fig. 1, Plate IX, is a photograph of interference rings obtained with this apparatus, corresponding to the green mercury line ($\lambda=5460.7424$) given by the mercury arc in a vacuum. The distance between the silvered surfaces was only 5 mm. Although this distance was so small the complex constitution of this radiation is clearly shown: each bright ring is accompanied by a fainter first interior ring, by a second interior ring, which is much fainter still, and finally by an exterior ring, which is double.[1] Each of these rings indicates the presence of a faint radiation which accompanies the principal line.

The existence of these complex radiations has been announced by Michelson, but we believe that hitherto no spectroscopic apparatus has permitted them to be *seen* and their position in the spectrum to be fixed without any hypothesis. Our interferometer permits this to be done, and thus probably constitutes the most powerful spectroscope hitherto constructed. The resolving power of this spectroscope increases with the distance between the silvered plates, and can thus be increased as long as the fringes remain visible; the finer the lines examined the further can the resolution be carried; in other words, the power of the apparatus is in every case sufficient to show the finest details that it is possible to distinguish.

University of Marseilles,
January 1901.

[1] Unfortunately the delicate details of the original photograph are lost in the reproduction.—Eds.

PLATE IX

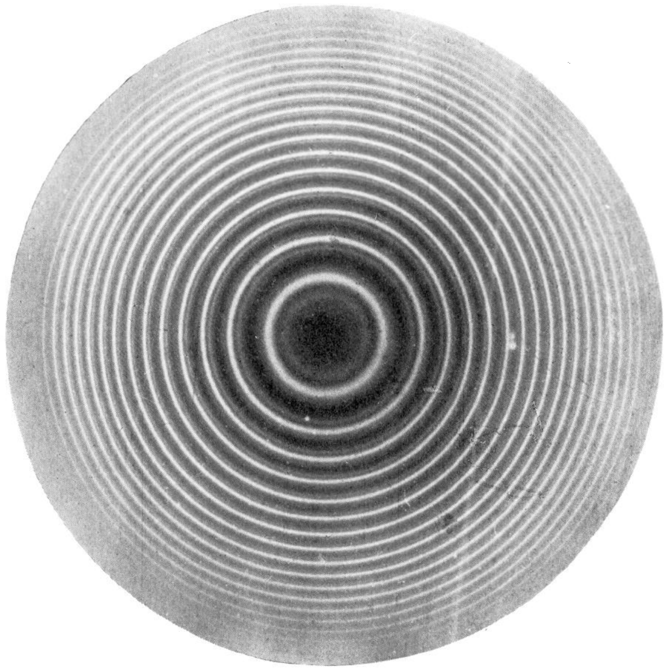

FIG. 1.—INTERFERENCE FRINGES OF GREEN MERCURY LINE

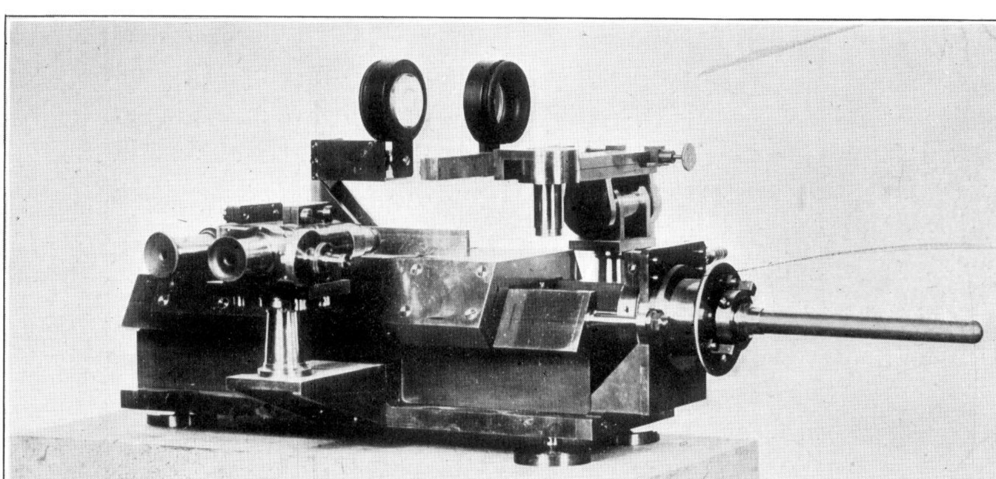

FIG. 2.—NEW FORM OF INTERFEROMETER