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A Demonstration Apparatus to Show Interference Between Polarized Light Beams

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The apparatus is a Michelson interferometer, modified in order to show interference between polarized light beams. Lecture experiments with linearly as well as circularly polarized light beams are described.

O aparelho é um interferômetro de Michelson modificado de modo a mostrar a interferência entre feixes de luz polarizada. Descrevem-se também experiências de leitura com luz polarizada seja linearmente, seja circularmente.

In this article is described a demonstration apparatus to show, in classroom, the interference between polarized light beams.

The generalized interference laws of Fresnel and Arago can be summarized as follows[1,5]:

i) Two light waves in the same state of elliptical polarization can interfere;

ii) Two light waves in orthogonal states of elliptical polarization cannot interfere.

iii) Two light waves in orthogonal states of elliptical polarization, coming from the same fully polarized wave and subsequently brought into the same plane, can interfere.

iv) Two light waves in orthogonal states of elliptical polarization, coming from the same unpolarized wave and subsequently brought into the same plane, cannot interfere.

The experiments described in this article illustrate these laws in the case of linearly and circularly polarized interfering light beams. The

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case of linearly polarized interfering light beams has been already treated by F. Y. Yap[6].

The experiments are very simple to perform and do not require any particular care. In the "Instruction Book"[7] of Metrologic it is carefully indicated how to adjust and align the lecture demonstration interferometer. To perform the experiments described in this article it is necessary: a) to obtain on the screen a regular interference pattern, b) to put the polarizers 1 and 2 into the two arms of the interferometer, c) to mount a linear polarizer 3 in front of the screen. With a diverging lens L_2 of -8 mm focal length one obtains on a 2 meter distant screen an interference pattern of about 25 cm diameter.

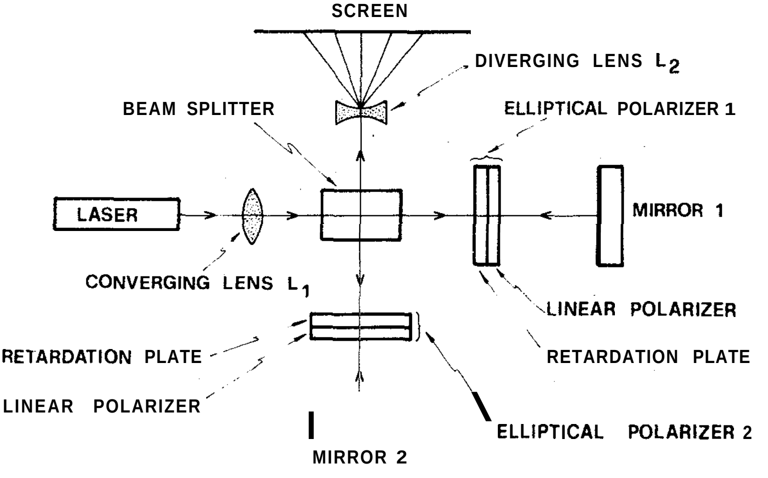

Fig. I – Diagram of a Michelson-type polarization interferometer

A schematic representation of the Michelson-type polarization interferometer[1,4] is shown in Fig. 1. Laser light falls upon a beam splitter where it is divided into two beams 1 and 2. Beam 1 passes through polarizer 1, is reflected from mirror 1, passes again through polarizer 1 and acquires a well defined state of polarization, then passes through the beam splitter and the diverging lens L_2 to the screen. Beam 2 passes through polarizer 2, is reflected from mirror 2, passes again through polarizer 2 and acquires a well defined state of polarization, then passes through the beam splitter and the diverging lens L_2 to the screen. If the mirrors 1 and 2 are not exactly perpendicular, so that the mirror 2 and the image of mirror 1 (with respect to the semi reflecting surface of the beam splitter) form a small angle, the interference pattern is a system of straight interference fringes. The diverging lens L_2 is usecl in order to give a large interference pattern. We used the Michelson-type interferometer model 60-712 of Metrologic Inc.. Experiments with fully polarized incident light have been made with a beam produced by a standard polarized helium-neon laser (University Laboratories model 241.4 mW output, polarized). The polarizers 1 and 2 were: i) linear polarizers HN 32; ii) circular polarizers HNCP 37 right, left. The circular polarizers are sandwiches consisting of a piece of linear polarizer glued to a retardation plate. The linear and the circular polarizers were obtained from Polaroid Corp.. The apparatus permits lecture demonstration on the generalized Arago and Fresnel laws[5]. The light intensity on the screen is much higher than that obtainecl with a Young-type polarization interferometer[5].

In a Michelson-type interferometer, the polarizing effects of the beam splitter must be taken into account[8]. We used the Metrologic beam splitter 00103 (half-silvered mirror). In all of our experiments we have checked the states of polarization of the two interfering beams just before they strike the screen. This has been accomplished by interrupting the paths of beam 1 and of beam 2 one at a time.

Let us now examine in detail some experiments.

EXPERIMENT 1 — The light incident on the interferometric apparatus is linearly polarized in the vertical direction. The polarizers 1 and 2 arí: two linear polarizers ($\sim$ 3 cm x 5 cm) with their transmission axes both vertical. The interfering beams are both vertically polarized. An interference pattern appears on the screen. The interference pattern is similar to that which is obtained without polarizers.

EXPERIMENT 2 — The light incident on the interferometric apparatus is linearly polarized at 45° with respect to the vertical. The polarizers 1 and 2 are two linear polarizers. The transmission axis of polarizer 1 is vertical and that of polarizer 2 is horizontal. The interfering beams are linearly polarized with perpendicular polarizations. No interferente pattern appears on the screen, the field of view has only uniform illumination. The fringe system reappears if the screen is viewed through a linear polarizer **3** mounted in front of the screen. The fringe visibility Vis a function of the azimuth φ (with respect to the vertical)of the linear polarizer **3.** The dependence of V on φ is (Ref. 5) V= |sin 241| .

The experiment can also be performed without the linear polarizers 1 and 2, simply by putting a $\lambda/4$ plate in the arm 2 of the interferometer. If the light beam incident on the interferometer is vertically polarized, the $\lambda/4$ plate has to be oriented with its fast axis at 45° with respect to the vertical. The intensity of the pattern is stronger in this case than in the previous one.

EXPERIMENT 3 — The light incident on the interferometric apparatus is vertically polarized. The polarizers 1 and 2 are two circular polarizers (for the wave length $A = 560$ my) *HNCP 37* with the same handedness (for example both left circular polarizers). The transmission axes of the linear polarizers contained in the circular polarizers 1 and 2 are oriented one at $+45^\circ$ and the other at -45° (with respect to the vertical). The final reflection of beam 1 from the half-silvered mirror of the beam splitter changes the handedness of its polarization. This has been checked by interrupting beam 2 and by observing the state of polarization of the light emerging from the diverging lens L_2; it was found that a right circular analyzer transmits light, while a left circular analyzer completely cuts out light. In a circular analyzer, the light is incident on the retardation plate side. The two interfering beams on the screen are with a good approximation in two states of circular polarization with opposite handedness. No interference pattern appears on the screen.

The interference pattern reappears if a linear polarizer is mounted in front of the screen [see Fig. 2]. The fringe visibility does not vary noticeably with the orientation φ of the linear polarizer [see eq. 19 Ref. (5)]. The phase of the fringe system is shifted by 180" if the linear polarizer is rotated by 90" [see Fig. 2].

The wavelength of the laser light used is 632 my. For this wavelength, the circular polarizers HNCP 37 are elliptical polarizers. This does not change noticeably the results because; i) the two interfering light beams are, in any case, to a good approximation, in two orthogonal states of elliptical polarization[5], and ii) the eccentricity of the ellipses describing their state of polarization is not too different from unity. For a quantitative analysis of this topic see Ref. (5).

The experiment could be also performed by substituting both the circular polarizers 1 and 2 with a $\lambda/8$ retardation plate.

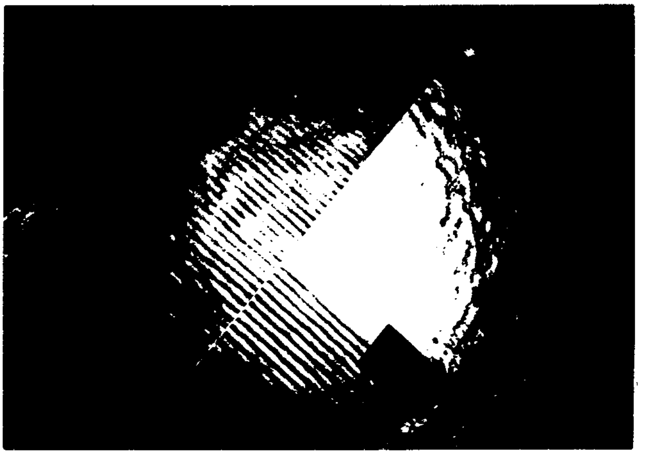

Fig. 2 – **Interference** pattern as seen on the screen (experiment 3). The interfering light beams are, to a good approximation, circularly polarized with opposite handedness. Twc linear polarizer; with their transmission axes orthogonal are fixed in front of the screen. The interference fringes are clearly visible on the screen behind the linear polarizers. The interference pattern behind one polarizer is shifted by 180" with respect to the interference pattern behind the other polarizer. No interference pattern appears in the region not covered by either linear polarizer. The distance between two adjacent dark fringes is 0.3 cm. The distance of the screen from the diverging lens Lis about 0.7 meters. **A** piece of scotch tape (width 1.9 cm), which was used to fix the polaroid on the screen is visible on the photograph. The fringe pattern was photographed by a camera mounted in front of it.

EXPERIMENT 4 — The light incident on the interferometric apparatus is vertically polarized. The polarizers 1 and 2 are two circular polarizers HNCP 37 with opposite handedness. The transmission axes of the linear polarizers contained in the circular polarizers are both vertically oriented. The final reflection of beam 1 from the beam splitter changes the handedness of its polarization. The two interfering beams are therefore with a good approximation in two states of circular polarization with the same handedness. An interference pattern appears on the screen.

EXPERIMENT 5 — The incident light beam is produced by a standard unpolarized helium-neon laser. We used the model 410 of Metrologic Inc.. When the two interfering light beams are in orthogonal states of polarization (experiments 2 and 3) no interference pattern appears on the screen. Moreover, it was found that the interference pattern reappears if a linear polarizer 3 is put in front of the screen. A more careful observation showed that the fringe system shifted, in a time of the order of 30-60 seconds, in a random way. If one considers the mean value of the intensity on the screen, made over times of the order of several minutes, one finds uniform value. Unpolarized laser light is at a given instant elliptically polarized. This state of elliptical polarization changes randomly in time. The correlation time τ is of the order of 30-60 seconds. The only reference we know about this interesting phenomenon, concerning the state of polarization of the light produced by an unpolarized laser, is the "Instruction Book" of Gottlieb[9] describing some applications of the laser of the Metrologic Inc.. The experiments described in this paper can be easily shown in a class of about 60 students. They can be useful to illustrate the phenomenological aspects of the generalized interference laws of Fresnel and Arago.

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