Michelson Interferometry

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In this paper, we demonstrate several applications of the Michelson Interferometer in analyzing monochromatic light. Firstly, we measure the wavelength of the monochromatic source by counting the number of fringes that pass a reference point as we move a platform-mounted mirror translationally. Secondly, we measure the refractive index of a glass slide by changing the angle by which the monochromatic light strikes the slide and counting the number of new fringes formed through a fixed distance. The main purpose of this paper is to familiarize undergraduate students with optical instruments like beam splitters, translational and rotational stages, and lenses. We also hope to induce understanding of primary concepts of wave interference.

I. INTRODUCTION

Michelson interferometer has long been a prominent instrument in undergraduate laboratories. Interferometers steered optical physicists into the span of modern physics. Principally, it validated Einstein's special theory of relativity and renounced the concept of ether in the classical experiment performed in 1887. The applications of an interferometer, however, are varied and can be used to discern wavelengths given precise measurements of distance or vice versa [2]. In addition, Michelson Interferometer can be used to measure the refractive index of a thin parallel-side plate of transparent material of known thickness. This is accomplished by observing the superimposed fringe pattern of light from a monochromatic source [1]. The presence of fringes should exist in theory since there is a point where all waves interfere irrespective of their wavelength.

Interference is one of the many consequences of wave nature of light. Michelson Interferometer can delicately determine the separation of wavelengths of non-monochromatic sources. The two or more waves present propagate in a way similar to that of sound waves. Intuitively, superposition of the interference patterns of each wavelength occurs and will thus rotate in phase or out of phase as the path lengths are altered [2].

Our experiment consists of displacing the movable mirror by a fixed amount and counting the number of fringes entering or leaving the centre of the fringes pattern. For the wavelength of the monochromatic source, a fixed mirror was used. To calculate the refractive index of the glass slide, this fixed mirror was replaced by the glass slide on a rotatable stage. The details are mentioned in section II.

II. THEORETICAL BACKGROUND

Interference is one of the many significant consequences of wave nature of light. Fortunately, these effects are accessible to students of different levels. Michelson Interferometer is a practical way of superimposing two light sources to observe interference. A schematic of Michelson interferometer is shown in Fig. 1. After passage through a beam splitter the primary ray of light moves along two orthogonal paths (the arms of the Interferometer) before rejoining to produce an interference pattern observed at the screen. The two arms should roughly be the same distance. The light rays should reflect in a similar fashion from both the mirrors in order to have a same phase shift of π. Unfortunately, the light falling at the screen is not parallel; the rays are in fact shifted θ away from the centre. The optical path difference, therefore, will be $2d\cos\theta$ and as modern optics dictate, maxima in the interference pattern occur when

$$m\lambda = 2d\cos\theta$$

where m is an integer and λ is the wavelength of the incident light [2]. As we vary d linearly, m varies linearly as well (albeit discreetly) so that a ring of maximal intensity disappears when 2d decreases by λ and appears when 2d is increased by λ [2]. In this way, we can measure distances on the order of the wavelength of the light source or measure the wavelength of the light source by varying the position of movable mirror by a known quantity and counting fringes that appear or disappear, depending on the direction moved. If we fix our observation to a central reference point on the detector, we have that

$$\Delta d = \frac{\lambda \Delta N}{2}$$

where Δd is the change in displacement of the movable mirror, λ is the wavelength is the laser wavelength and ΔN is the number of fringes passing a reference point [3]. This can be rearranged to get

$$\lambda = \frac{2\Delta d}{\Delta N}.$$

Total increase in the optical path length is

$$\frac{n_g t}{\cos\theta_r} + t\tan\theta\sin\theta - t\tan\theta_r sin\theta - n_g t - \frac{t}{cos\theta} + t = \frac{N\lambda}{2}$$

where n_g is the refractive index of the glass slide, θ_r is the reflected angle, θ is the angle rotated away from the centre in radians and t is the thickness of the glass [4].
Using Snell's law, $n_g \sin\theta_r = \sin$, this above equation can be reduced to

$$n_g(1-\cos\theta)2t - N\lambda = (2t - N\lambda)(1-cos\theta) + \frac{N^2\lambda^2}{4t}.$$

The last term is very small as compared to the other terms and can be neglected. Hence, we get

$$n_g = \frac{(2t - N\lambda)(1-cos\theta)}{2t(1-cos\theta) - N\lambda}.$$

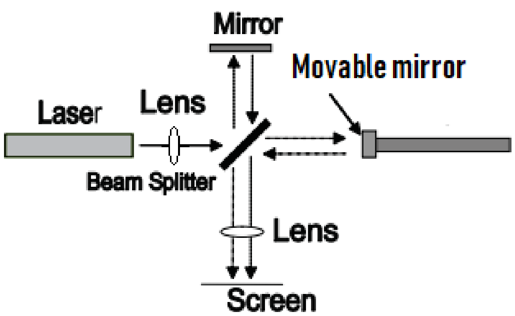

FIG. 1. Schematic of Michelson Interferometer.

III. EXPERIMENT AND PROCEDURE

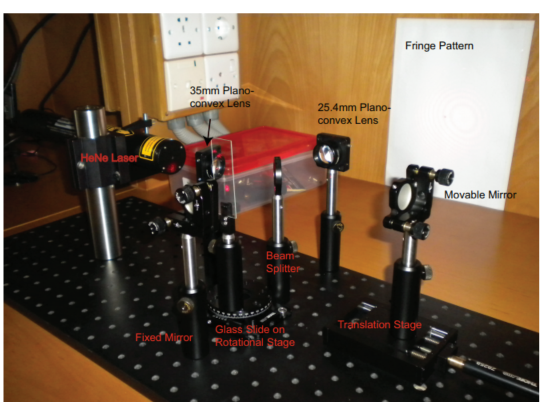

FIG. 2. Laboratory setup of Michelson Interferometer.

The experiment is conducted in two parts. First part focuses on calculation of wavelength of the laser. The second part is more focused on the calculation of the refractive index of a glass slide of known thickness. Fig. 2 [6] shows the laboratory set up that was used to conduct the experiment. We used a HeNe laser of unknown wavelength, initially, to serve as the monochromatic source. A non-polarizing beam splitter was placed right in front of the laser source. A plano-convex lens of focal length 35mm was placed between the source and the beam splitter. The incident beam on the beam splitter splitted into two orthogonal paths. One of the two parts of the light reflected back from a mirror and the other reflected back from a movable mirror, which was mounted on a translation stage that was being operated by the computer controlled servo motor. The two reflected rays superimposed at the beam splitter and were observed at the screen after being enlarged by a plano-convex lens of focal length 25.4mm placed between the screen and the beam splitter. The laser was optically aligned and visible fringes could be observed. Fig. 3 shows the circular fringes that appeared on the screen. This was followed by the use of a computer software, APT Configuration Utility, to move the movable mirror by a fixed displacement. In the first part, the number of fringes entering or leaving the centre of the fringe pattern can be recorded. This was done a number of times to accurately calculate the wavelength of the laser. In the second part, the fixed mirror was replaced by a glass slide, of thickness (1.05 ± 0.01)mm, mounted on a rotatable stage. For every 5^o change in the angle of incidence, the number of fringes entering or leaving the center of the pattern for a fixed displacement of the movable mirror were jotted down. This was also carried out repeatedly to minimize the error in the number of fringes recorded. The results were then used to calculate the refractive index of the glass slide.

IV. RESULTS

The thickness of the glass slide was measured using a vernier caliper which turned out to be (1.05 ± 0.01)mm. Table 1 shows the displacement of the movable mirror and the number of new fringes formed, for the first part of the experiment.

The average number of N was calculated to be (32 ± 1) and consequently λ was found to be $(6.2 \pm 0.2) \times 10^{-7}$m.
The change in angle of incidence, the number of fringes entering or leaving the centre of the fringe

FIG. 3. Observed fringe pattern.

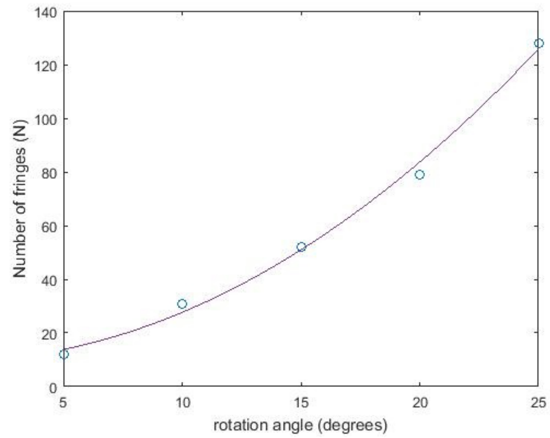

FIG. 4. Relationship between N and θ.

pattern, and the respective average number of fringes entering or leaving and the respective value of n_g are tabulated in Table 2.

$\Delta d/mm$	**N**
0.01	33
0.01	31
0.01	30
0.01	32
0.01	33

TABLE I. Values of displacement of movable mirror and number of fringes entering/leaving.

Using these values and the formula mentioned in Section 2, the refractive index of the glass slide was calculated to be (1.69 ± 0.02). The relationship between N and θ can be seen in Fig. 4.

$\Delta\theta/^o$	N_1	N_2	N_3	N_4	N_5	N_{avg}	n_g
5	13	10	11	15	12	12	1.68
10	34	30	31	30	31	31	1.71
15	53	52	57	54	52	52	1.72
20	80	78	79	77	80	79	1.69
25	130	131	128	127	127	128	1.71

TABLE II. Values of change in angle of incidence and number of fringes entering/leaving.

V. CONCLUSION AND DISCUSSION

The experiment described a novel yet simple method of determining the refractive index of glass slide using the Michelson Interferometer. The comprehensibility of this experiment allows undergraduate students to grasp the non-trivial manifestation of interference and interferometers. This method is finer than the one carried out using white light because it is easier to see the fringes pattern and detect the fringes entering or leaving the centre. Also, we note that given a constant d, m, and λ, cos θ is constant, thus, these maxima and hence, the fringes between the maxima, are spherically symmetric. We have demonstrated an accurate method for measuring the refractive index of a glass slide, of known thickness, using a Michelson Interferometer. Conversely, the thickness of a glass slide can be determined given that the refractive index is known. Optical alignment is vital, and often takes time, in order to observe the fringes pattern. The phase shifts have to be same, after the incident ray on the beam splitter splits into two orthogonal parts, for the waves reflected from the mirrors to interfere.

Further advancements can be made based on our understanding from this experiment. The Michelson Interferometer is a simple construction of optical instruments. Similar arrangements can be used to produce interference patterns that can be measured to extract more information on light. Undergraduate students can construct a tunable narrow band filter using a specific arrangement of instruments in an interferometer. Though the most intriguing applications of Michelson Interferometer can not be assembled at undergraduate level e.g. detection of gravitational laws (LIGO). However, an fascinating application of the Michelson Interferometer's method could be the measurement of close double stars which can be conducted at the graduate level. This can be done by using a defined assembly of Michelson Interferometer to measure the separation of components of *Capella* (the brightest point of light in the constellation of Auriga) [5]. Other applications of astronomical interferometry can be considered too.

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