

10. Michelson Interferometer

Background

Coherence
Phase relationship
Path difference
Interference
Virtual light source
Refractive index
Fresnel's biprism

Aim of the experiment

- (i) To determine the wavelength of the laser source by observing the fringe pattern obtained in the Michelson interferometer.
- (ii) To determine the base-angle of a Fresnel's biprism by introducing it in one of the arms of the Michelson interferometer.

Apparatus required

Michelson interferometer
Laser, He-Ne 1.0 mW
Swinging arm
Mounted Lens
Lens holder
Slide mount
Optical profile bench
Screen
Barrel base
Fresnel's biprism
Sliding mount with vernier for the biprism

Theory

If two waves of the same frequency ω but of different amplitude and different phase impinge on one point they are superimposed, or interfere, so that:

$$y = a_1 \sin (\omega t - \alpha_1) + a_2 \sin (\omega t - \alpha_2)$$

The resulting wave can be described as

$$y = A \sin (\omega t - \alpha)$$

with the amplitude

$$A^2 = a_1^2 + a_2^2 + 2 a_1 a_2 \cos \delta \dots\dots\dots (1)$$

and

$$\delta = \alpha_1 - \alpha_2$$

In a Michelson interferometer, light is split up into two beams by a half-silvered glass plate (amplitude splitting), reflected by two mirrors, and passed again through the glass plate to produce interference phenomena behind it, as shown in Fig. 1. A lens is inserted between the light beam and the glass plate so that the light source lies at the focal point, since only enlarged light spots can exhibit interference rings.

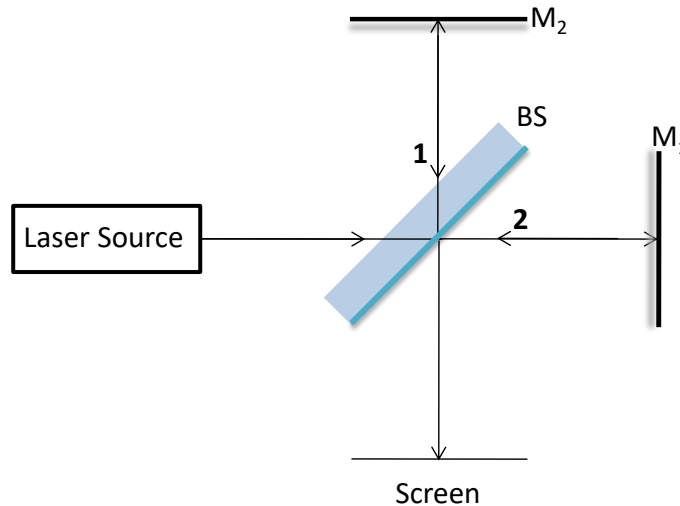


Fig. 1: The top view of the Michelson Interferometer showing the path of the light. M_1 and M_2 are mirrors and BS is the half-silvered glass plate / beam-splitter.

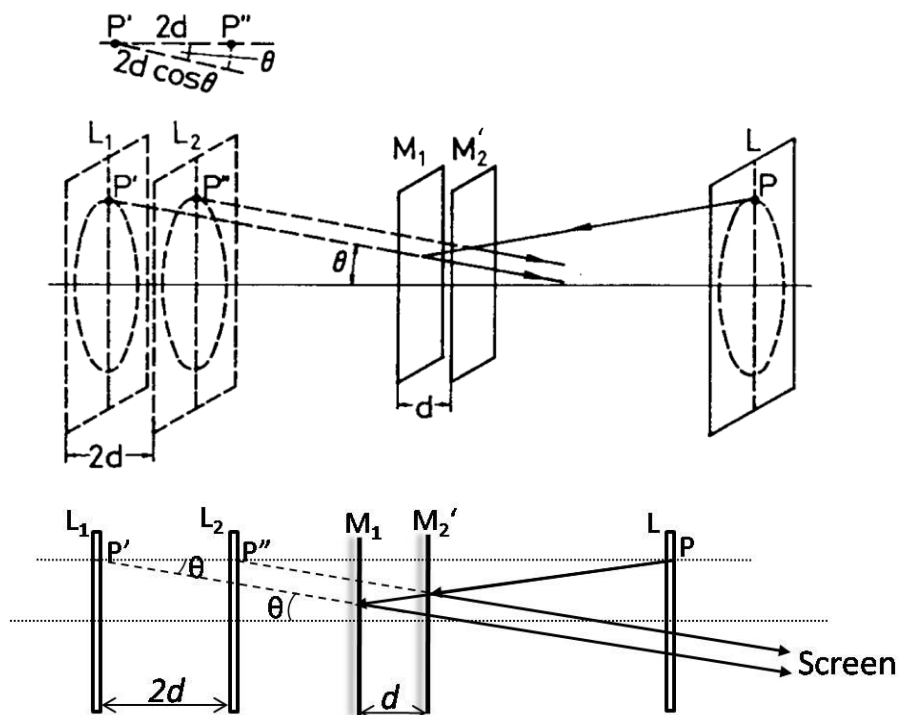


Fig. 2: Conceptual rearrangement of the Michelson Interferometer. M_1 is the real mirror, M_2' is the virtual image of M_2 , L is the real light source, and L_1 and L_2 are virtual light sources.

If the actual mirror M_2 is replaced by its virtual image M'_2 which is formed by reflection at the glass plate, a point P of the real light source is formed as the points P' and P'' of the virtual light sources L_1 and L_2 .

Based on the different light paths, the phase difference, using the symbols of Fig. 2, is:

$$\delta = \frac{2\pi}{\lambda} 2d \cos \theta \dots\dots\dots (2)$$

where λ is the wavelength of the light used in the experiment.

The intensity distribution for $a_1 = a_2 = a$ according to (1) is:

$$I \sim A^2 = 4 a^2 \cos^2 \frac{\delta}{2} \dots\dots\dots (3)$$

In Fig. 1, ray 2 experiences an additional phase change with respect to ray 1 due to external reflection, and as a result, **minima** occur if δ is a multiple of 2π , i.e., from equation (2), if

$$2d \cos \theta = m \lambda; \quad m = 1, 2, \dots \dots\dots (4)$$

i.e. dark circles are produced for a fixed value of m and δ since θ remains constant (see Fig. 2).

If the position of the movable mirror M_1 is changed so that d for example decreases then, according to equation (4), the diameter of the ring will also decrease since m is fixed for this ring. A ring thus disappears each time d is reduced by $\lambda/2$. The ring pattern disappears if $d=0$. The discussion so far is true for the case when M_1 and M'_2 are parallel to each other (or M_1 and M_2 are perpendicular to each other). It is to be noted that the shape of the fringe pattern depends on the alignment between M_1 and M'_2 as shown in Fig. 3. If M_1 and M'_2 are not parallel, curved bands are obtained which are converted to straight bands when $d = 0$.

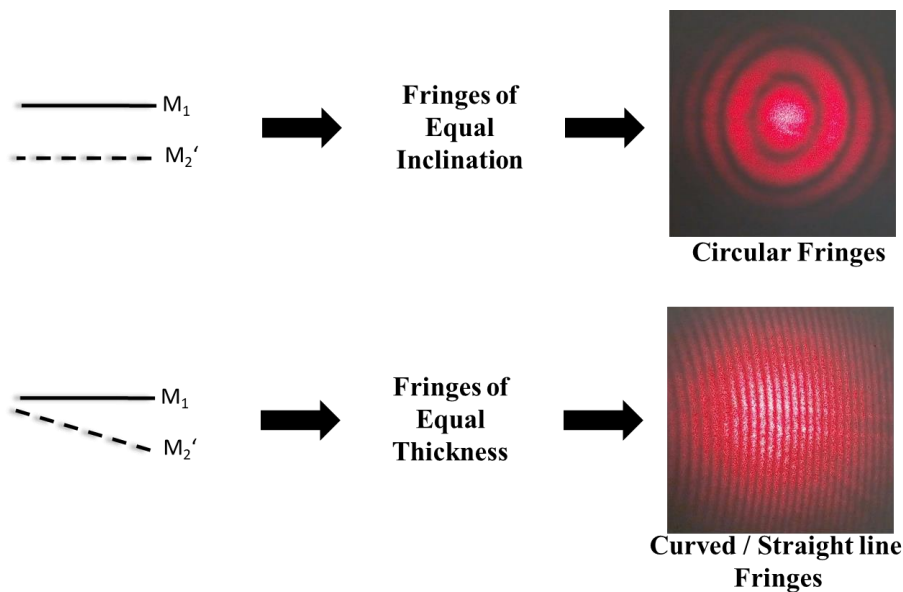


Fig. 3: Dependence of the fringe shape on the alignment between M_1 and M'_2 .

Determination of the base-angle of Fresnel's biprism using Michelson interferometer:

Optical properties such as refractive index and thickness of an optical element can be studied by introducing the element in one of the arms of the interferometer. Fig. 4 shows a Fresnel's biprism introduced in one of the arms of the Michelson interferometer between BS and M₁. This arm will be referred to as the probe-arm of the interferometer. As the biprism is translated, with its base perpendicular to the incident beam as shown by the arrow in Fig. 4, the circular fringes on the screen continuously appear/collapse due to the varying optical path in the probe-arm.

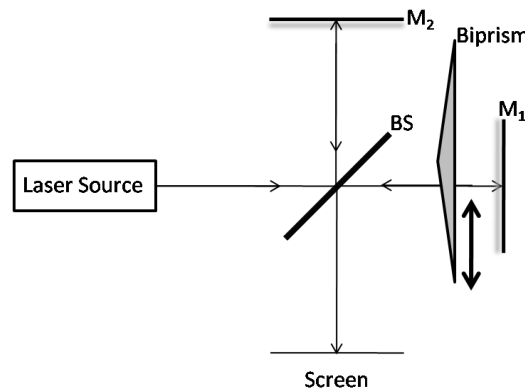


Fig. 4: Schematic of the experimental arrangement used to determine the base-angle of a Fresnel's biprism introduced in the probe-arm of the Michelson interferometer.

If the biprism is moved with the help of a calibrated translation stage, and the number of fringes that appear/collapse are counted, then the change in path length in the probe-arm of interferometer containing the biprism can be estimated. An exaggerated geometrical picture of the path length variation is shown in Fig. 5 below:

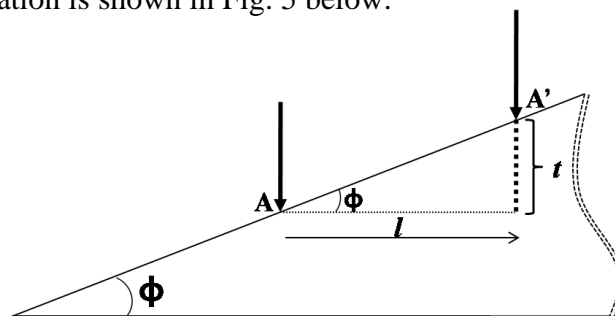


Fig. 5: An exaggerated geometric representation of one of the base-angles of the Fresnel's biprism.

To start with, let the laser spot be centered at point A. Now, if the biprism is translated by a length l , so that the laser spot is centered at A', then the change in path length for the laser beam traversing the prism twice would be $2t$. Considering the refractive index of the material of the biprism to be n , equation (4) can be rewritten for the extra path difference as: (for $\theta = 0$ at the centre of the fringe pattern)

$$2(n-1)t = m\lambda; \quad m = 1, 2, \dots$$

$$t = \frac{m\lambda}{2(n-1)} \dots\dots\dots (5)$$

With the knowledge of the wavelength of the laser source (λ) and the refractive index of the material of the biprism (n), the base-angle ϕ of the biprism can be calculated using:

$$\phi = \frac{t}{l} \dots\dots\dots (6)$$

Procedure

The experimental set up is as shown in Fig. 6. Precise and careful alignment of the arms of the interferometer is essential to observe the interference fringes.



Fig. 6: Experimental set-up for measuring wavelengths with the Michelson interferometer.

(i) Determination of the wavelength of the laser source

1. For alignment:
 - a. Remove the lens placed between the laser source and the half-silvered glass plate.
 - b. Make sure that the laser beam strikes the half-silvered mirror at an angle of 45° . The resultant two split beams are reflected by the mirrors and impinge on the screen.
 - c. By means of the two adjusting screws fitted to one of the mirrors, make the two points of light falling on the screen to coincide.
 - d. Now, place the lens in between the laser and the half-silvered mirror. The points of light will be enlarged along with the observation of interference on the screen (bands, circles).
 - e. Carefully readjust the screws fitted to one of the mirrors to obtain a sharp interference image of concentric circles.

2. To measure the wavelength, turn the micrometer screw attached to one of the mirrors to any initial position at which the centre of the concentric circles is dark. Turn the micrometer screw further in the same direction and count the bright-dark periods thus produced.

3. Read the distance travelled by the mirror using the micrometer screw and divide the value by ten (*lever reduction 1:10*). If the central point of the circles moves outside the light spot area, readjust the alignment.

4. Repeat the steps 2 and 3 several times, tabulate the observed data in Table 1. Finally, obtain an averaged value of the wavelength of the laser source using the equations given in the table.

(ii) Determination of the base-angle of the Fresnel's biprism

1. Do not alter the experimental arrangement, after completing the experiment on the measurement of the wavelength of the laser source. Introduce the Fresnel's biprism mounted on a translation stage in one of the arms of the interferometer as shown in Fig. 4.
2. Carefully align the biprism so that its base is parallel to the mirror M_1 , as shown in Fig. 4.
3. The interference pattern disappears due to the introduction of the biprism. Now, by means of the two adjusting screws fitted to one of the mirrors, make the two points of light coincide on the screen, and make fine adjustments till you get back the interference pattern.
4. Now, to find the base angle of the prism, turn the translation stage attached to the base of the biprism to any initial position at which the centre of the concentric circles is dark. Turn the translation stage further in the same direction and count the bright-dark periods thus produced.
5. Read the distance travelled by the biprism using the scale on the translation stage.
6. Repeat the steps 4 and 5 several times, tabulate the observed data in Table 2. Finally, obtain an averaged value of the change in optical path with the translation of the biprism and determine the base-angle using the formula given in the table.

Observations

Table 1

Determination of wavelength of the laser source

Least count of the micrometer screw =

Number of fringes collapsed/ appeared (m)	Micrometer Position						$ b - a = d_1$	$d = d_1/10$	Wavelength ($\lambda = 2d / m$)
	Initial			Final					
	MSR	CSR	Total (a)	MSR	CSR	Total (b)			

Important note: The distance travelled by the mirror must be read off on the micrometer screw and divided by ten (lever reduction 1:10).

Table 2

Determination of the base-angle of the Fresnel's biprism

Wavelength of laser source (λ) =

Refractive index of the material of the Fresnel's biprism (n) =

Least count of the translation stage =

Number of fringes collapsed/ appeared (m)	Translation stage Position						$ b - a = l$	$t = \frac{m \lambda}{2(n - 1)}$	$\phi = \frac{t}{l}$
	Initial			Final					
	MSR	VSR	Total (a)	MSR	VSR	Total (b)			

Results

The averaged value of the wavelength of the laser source obtained from Table 1 is nm.

The averaged value of the base-angle of the Fresnel's biprism obtained from Table 2 is.....

Error calculations

(i) The wavelength of the laser source is given by: $\lambda = \frac{2d}{m}$

Find: $\frac{\delta\lambda}{\lambda} = 2 \frac{\delta d}{d} + \frac{\delta m}{m}$

The '2' factor that appears with $\frac{\delta d}{d}$ term in the above expression is related to the fact that d is obtained as a difference of two scale readings, each with an error equal to the least count of the instrument.

(ii) The base-angle of the Fresnel's biprism is given by: $\phi = \frac{t}{l}$; $\phi = \frac{m \lambda}{2(n-1)l}$

Find: $\frac{\delta\phi}{\phi} = \frac{\delta m}{m} + \frac{\delta\lambda}{\lambda} + 2 \frac{\delta l}{l}$

The '2' factor that appears with $\frac{\delta l}{l}$ term in the above expression is related to the fact that l is obtained as a difference of two scale readings, each with an error equal to the least count of the instrument.

Precautions

- (i) Never look directly into a non attenuated laser beam.
- (ii) Align the interferometer very carefully. Do not disturb it once the fringes are obtained.
- (iii) The interferometer is very sensitive to vibrations on the table and also on the floor. Avoid touching the table on which the experiment is set-up.

Questions

1. What do you understand by interference of light?
2. What is a coherent light source?
3. What is the role of coherence of the light source in the Michelson interferometer?
4. What would happen if a thin-glass-slide of refractive index 1.55 (at 632.8 nm) and thickness 20 microns is introduced in one of the arms of the Michelson interferometer? Can you make an estimate of the number of fringes that collapse / appear?
5. According to you, what could be the possible applications of studying interferometry?

References

1. Optics by E. Hecht
2. Optics by A. Ghatak
3. PHYWE, LEP 2.2.05, Michelson Interferometer