EXPERIMENT 8

MICHELSON INTERFEROMETER

PURPOSE

To determine the wavelength of the laser using Michelson Interferometer and refractive index of air.

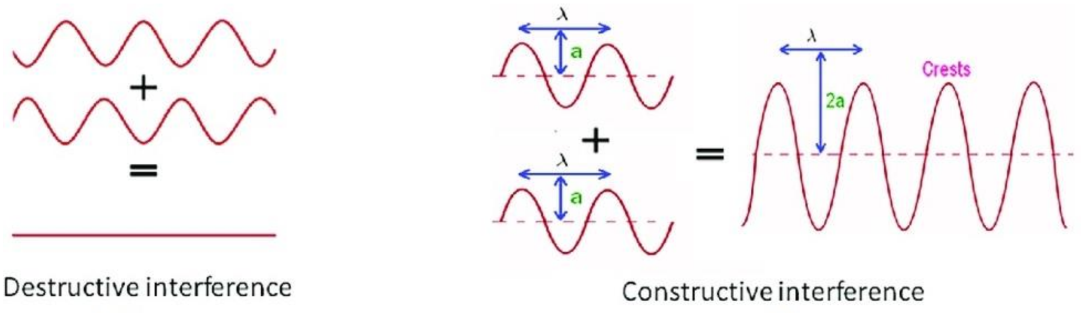
EQUIPMENT

Laser source, Michelson Interferometer kit, Optical bench.

THEORY

Interference

Light is an electromagnetic wave that is associated with electric and magnetic fields. When a single source of light is used, the distribution of energy in a medium is uniform. Instead, if two or more coherent sources are present, the distribution of energy will not be uniform due to the superposition of the waves. This phenomenon of modification in the distribution of light energy due to the superposition of two or more waves is termed as interference. If the crest of one wave meets with the through of the other, the resultant intensity will be zero and the waves are said to interfere destructively. Similarly if the crest of one wave meets with the crest of the other, the resultant intensity will be a maximum. Now the waves are said to interfere constructively. This superposition of waves results in interference fringes. Thus, an interference phenomenon is observed only when the source are coherent. **Fig.1** shows the schematic diagram of destructive and constructive interference.



Destructive interference **(a)** Constructive interference **(b)**

Fig.1 Schematic diagram of destructive and constructive interference.

Path difference between two waves are given eq.(1) and eq.(2) for constructive and destructive interferance, respectively.

$$Path\ difference = n\lambda \qquad (n = 0, 1, 2 \ldots) \qquad (1)$$

$$Path\ difference = \left(n + \frac{1}{2}\right)\lambda \qquad (n = 0, 1, 2 \ldots\ldots) \qquad (2)$$

Michelson Interferometer

An important instrument involving wave interference is the Michelson interferometer invited by A. A. Michelson in 1881. Originally, the device helped to provide one of the key experimental foundations of the theory of relativity. More recently, Michelson interferometers have been used to measure wavelengths or other lengths with great precision.

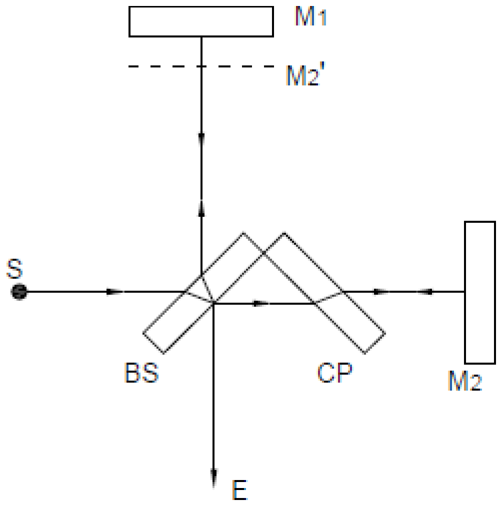


Fig 2 Schematic diagram of Michelson interferometer.

Fig 2 shows a schematic Michelson interferometer. A ray of light from a monochromatic source ***S*** is split equally into two rays by a beam-splitter ***BS***, which is inclined at 45° to the incident light beam. One beam is reflected by ***BS*** vertically upward toward a fixed mirror M_1, the second ray is transmitted horizontally through ***BS*** toward a movable mirror M_2. After reclecting from M_1 and M_2, the two rays eventually recombine at ***BS*** to produce an interference pattern, which caan be viewed by an observer's eye ***E***. The purpose of using a compensator plate ***CP*** here is to ensure that the two rays pass through the same thickness of glass, as ***CP*** is cut from the same piece of glass as ***BS*** so that their thicknesses are identical.

The interference condition for the two rays is determined by their path differences. In general, the interference pattern is a target pattern of bright and dark circular fringes. As M_2 is moved, the fringe pattern collapses or expands, depending upon the moving direction of M_2. In either case, the fringe pattern shifts by one-half fringe each time M_2 is moved a distance that is equal to quarter of the wavelength of light. As a result, the wavelength of light can be measured by counting the number of fringe shifts for a given displacement of M_2. On the other hand, if the wavelength of light is known, mirror displacement can be measured precisely, within a fraction of the wavelength of light using the same procedure.

Fabry-Perot Interferometer

When one beam of light passes through a plane-parallel plate with two reflecting surfaces, it is reflected many times between the two surfaces and hence multiple-beam interference occurs. The higher the surface reflectance is, the sharper the interference fringes are. That is the basic principle of the Fabry-Perot interferometer.

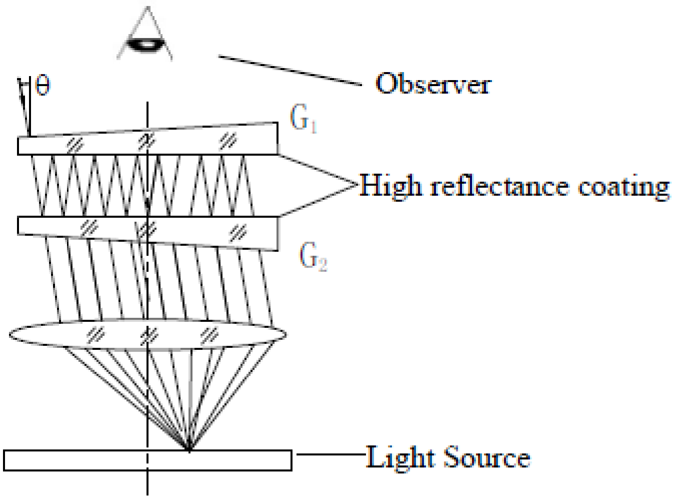


Fig 3 Schematic diagram of Fabry-Perot interferometer.

As shown in **Fig 3**, two partially reflecting mirrors ***G₁*** and ***G₂*** are aligned parallel to each other, which form a reflectively cavity. When monochromatic light is incident on the reflective cavity with an angle ***θ***, many parallel rays pass through the cavity to become the transmitted light. The optical path difference between two neighboring rays is given by ***δ***:

$$\delta = 2nd\cos\theta \qquad (3)$$

Thus, the transmitted light intensity is:

$$I' = I_0 \frac{1}{1 + \frac{4R}{(1-R)^2} sin^2 \frac{\pi\delta}{\lambda}} \qquad (4)$$

Where ***I₀*** is the incident light intensity, ***R*** is the mirror reflectivity, ***n*** is the refractive index of the medium in the cavity, ***d*** is the cavity length or mirror spacing, and ***λ*** is the wavelength of the monochromatic light.

Thus, ***I'*** varies with ***δ***. When

$$\delta = m\lambda \qquad (m = 0, 1, 2 \ldots.) \qquad (5)$$

I' becomes a maximum so that constructive interference of the transmitted light occurs. When

$$\delta = (2m' + 1)\,\lambda/2 \qquad (m = 0, 1, 2 \ldots\ldots) \qquad (6)$$

I' becomes a minimum and destructive interference of the transmitted light is observed.

PROCEDURE

This equipment combines a Michelson interferometer anf Fabry-Perot interferometer on one square base, which is made of a thick steel plate with a rigid-frame. **Fig 4** shows layout diagram of the instrument.

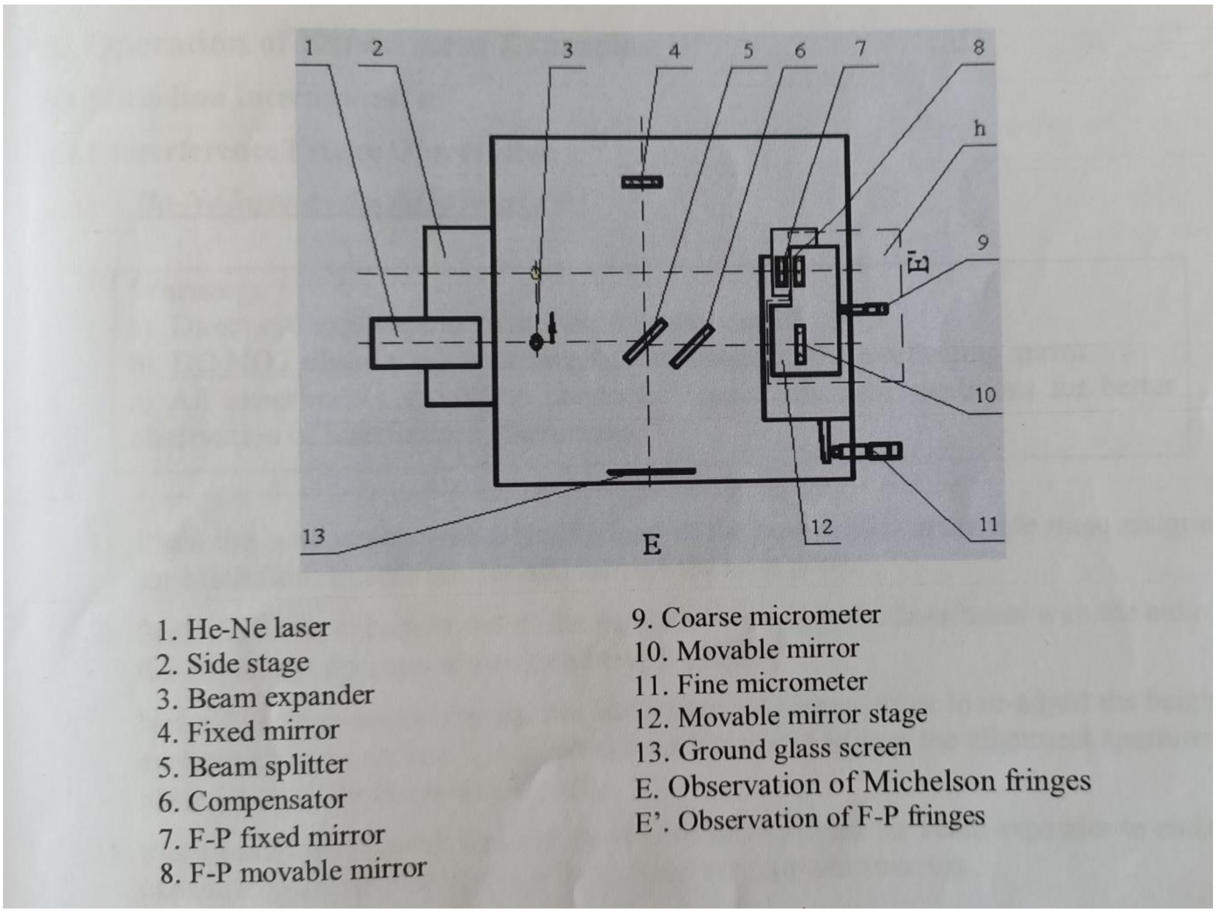


Fig 4 Layout diagram of the instrument.

Calculation of the wavelength of the light source

1. Place the laser mount with a He-Ne laser in the post holder on the side stage assigned for Michelson interferometer and turn on the laser power.
2. Push the beam expander out of the path while aligning the laser beam with the aid of alignment aperture at two mounting locations. **Note:** This may involve tilting the laser tube and so remember to re-adjust the height each time tilting occurs. The aligned laser beam shoul pass the alignment aperture palced at both locations of the path.
3. Place beam expander in front of the He-Ne laser. Adjust the beam expander to maket he expanded beam hit the center of both fixed and movable mirrors.
4. Push beam expander out of the path while placing a piece of paper card in front of the movable mirror.
5. Place the ground glass screen in the location as shown in Fig 4. A beam spot should be seen on the screen, which is reflected from the fixed mirror. There are also other spots on the screen with less brightest spot is seen on the center of the screen.
6. Remove the cards and observe the White screen. Two bright spots shoul appear (and less bright multiple reflections). Adjust the movable mirror until the two bright spots coincide with each other at the center of white screen.
7. Put the beam expander back into the laser beam path and make fine alignment of the beam expander if necessary. The fringe pattern can be observed on the white screen. **Note:** when adjusting the expanded beam spot, hold a piece of paper behind the movable mirror to identify the location of the beam spot.

8. Adjust the coarse micrometer so that images (a) to (e) are viewed in succession.
9. Set the fine micrometer to the middle of the scale (between 10 mm to 15 mm).
10. Re-adjust the coarse micrometer as closely as possible to reproduce image (c).
11. Use the fine micrometer to produce fringes of equal inclination. Record the reading d_0 of the fine micrometer.
12. Count the number of fringes thah expand (or collapse) in the center of the field of view as the fine micrometer is turned slowly. After counting 50 fringes record the micrometer reading again.
13. Continue the above process through 250 fringes, and record the micrometer reading after each set of 50 fringes has been counted.
14. Calculate the actual mirror movement, Δd, as

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

Where λ is the wavelength of the source and ΔN is the number of frimges counted. On the other hand, the wavelength of the source can be determined by

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

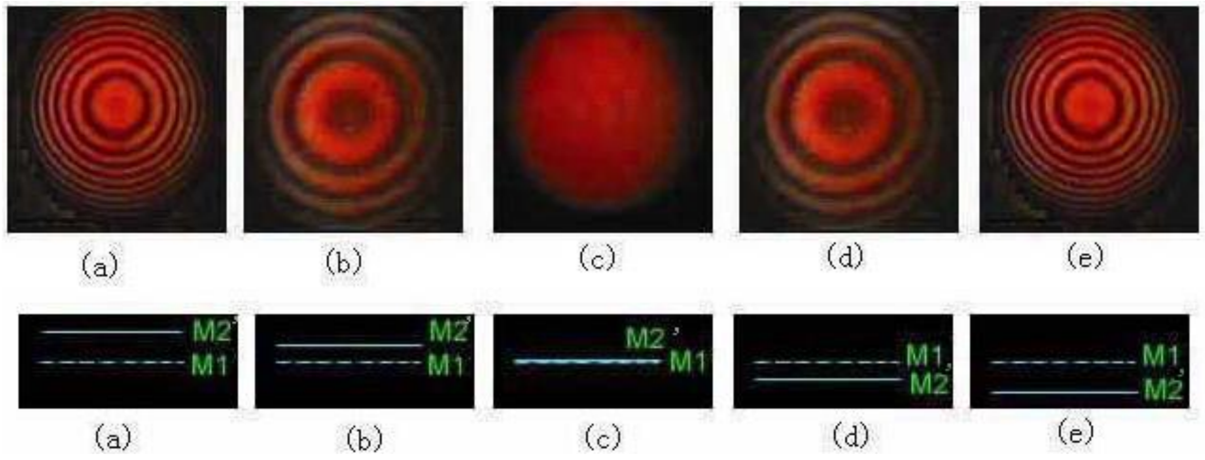


Fig 5 Illustration of equal-inclination interference.

Calculation of the refractive index of air

1. Align the interferometer.
2. Adjust the movable mirror M_2 to obtain clear equal-inclination fringes on the center of the ground glass screen using a He-Ne laser.
3. Put the air chamber with known length l in its holder 8for accurate measurement, the end plates of the air chamber must be perpendicular to the laser beam).
4. Pump in air to the chamber and then record the rading of the gauge ΔP.
5. Release the valve and slowly deflate the air in the chamber till the gauge reads zero. During the process, count N. The refractive index of air in the experiment is given by,

$$n = 1 + \frac{N\lambda}{2l} x \frac{P}{\Delta P}$$