Chapter 1

Interferometry

Objectives

1. Find the wavelength of the laser source
2. Find the refractive index of the material of glass slide.

Introduction/Theory/Background

Theoretical background for Michelson interferometer setup

The Michelson interferometer causes interference by splitting a beam of light into two parts. Each part is made to travel a different path and brought back together where they interfere. We observe an interference pattern due to the different lengths of path travelled and phase difference cause by reflection by a denser medium. The Michelson interferometer operates on the principle of division of amplitude rather than on division of wave front. A diagram of the apparatus is shown in the figure 1.1.

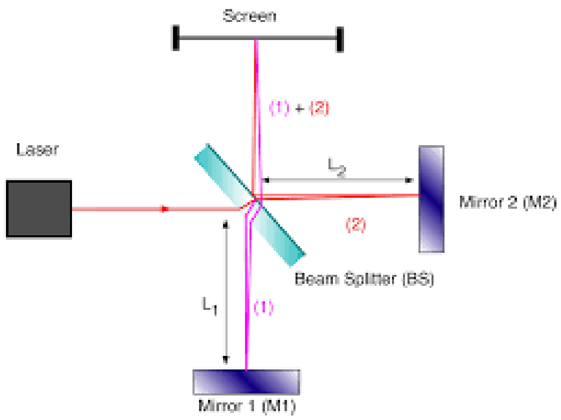

Figure 1.1: Michelson interferometer setup.

Light from a light source (L) strikes the beam splitter (designated by BS) at 45° and is split into two parts. The beam splitter allows 50% of the radiation to be transmitted to the translatable mirror M2. The other 50% of the radiation is reflected from the *rear surface* of the beam splitter to the fixed mirror M1. Both these mirrors, M1 and M2, are highly silvered on their front surfaces to avoid multiple internal reflections. A beam widener is used to create an extended source of light.

Why is an extended source critical?

The two beams coming from M1 and M2 are superposed and one can observe the interference fringe pattern on the screen. The character of the fringes is directly related to the different optical path lengths travelled by the two beams and therefore is related to the cause of a difference in the optical path lengths.
As one can see, both these rays do not travel exactly the same distance through the glass. The *ray 1* travels three times through the glass whereas *ray 2* travels only once, which introduces an extra phase difference of π.

Now, we want to figure out the nature of the interference fringes obtained. Let the real mirror M2 be replaced by its virtual image M2' formed by the reflection in the beam splitter. Let us consider the case where $M2'$ is parallel to M1. For simplicity, the extended light source L is behind the observer's position. L1 and L2 are the virtual images of L formed by $M1$ and $M2'$, and are coherent. Let d be the distance between $M1$ and $M2'$, therefore the distance between L1 and L2 is $2d$. Consider the figure 1.3. Let θ be the angle between the incident beam originated at the point P and the reflected beams from $M1$ and $M2'$. Then the optical path difference between the parallel light beams coming to the observer from points P'and P" is $2dcos\theta$. Now, taking the phase change (as discussed above) into account, the condition for **destructive** interference becomes:

$$2dcos\theta = n\lambda \tag{1.1}$$

where n is an integer and λ is the wavelength of the monochromatic light source.

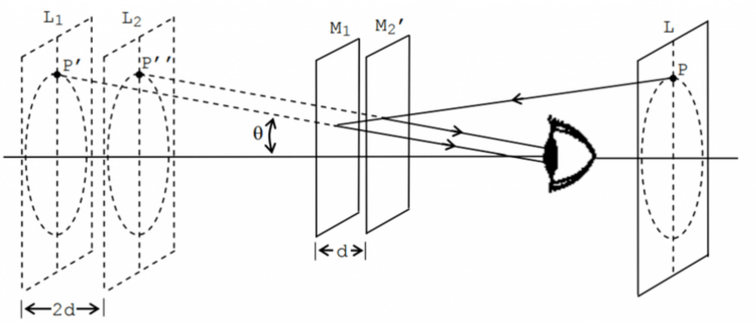

Figure 1.2: Formation of circular fringes in the Michelson interferometer.

For a fixed value of n, λ and d, the value of θ is a constant, and the contour of the maximum or minimum point becomes a ring. The centre of the ring is in line with the observer and perpendicular to the mirror plane. Each circular ring corresponds to a particular value of θ. Hence these circular fringes are known as fringes of equal inclination.

If the two mirrors M1 and M2 are not aligned precisely perpendicular to one another, the path difference will depend on the particular region of mirror M1 (and the corresponding region of M2) which we are observing. The field of view, then, seen by looking at mirror M1 from observer's position will be made up of a series of alternately bright and dark fringes, nearly straight and parallel, similar to those produced by interference from a simple wedge. Such fringes are referred to as fringes of equal thickness, or straight-line fringes. These two cases of circular and straight-line fringes have been shown in the figure 1.3.

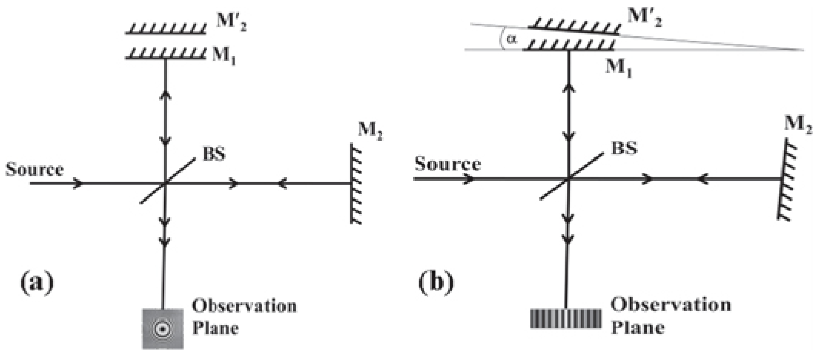

Figure 1.3: (a) Circular fringes are obtained when the two mirrors are precisely aligned perpendicular to one another, ensuring the path differences over different regions of the mirror are constant. (b) Straight fringes are obtained when the two mirrors are not aligned precisely perpendicular to each other and the path difference will depend on the particular region of mirror which we are observing from the position of the screen.

If the mirror M2 is moved a distance Δd, then the intensity of the light detected at the screen will increase and decrease as successive interference maxima and minima are experienced, which is what we see as the collapse of each bright or dark ring. Counting the number N of consecutive bright or dark patterns collapsing (or emerging) at the centre allows us to formally write:

$$2\Delta d = N\lambda \tag{1.2}$$

Δd is the linear distance moved, but since we rotate a circular scale of the micrometer screw to change the mirror's position, we also use a calibration constant (C) in order to precisely convert our readings to a linear scale and hence, the formula becomes:

$$2\Delta d C = N\lambda \tag{1.3}$$

The value of C here is 0.0241.

Formula relating collapsing of fringes to refractive index

Let OP be the original direction of light normal to plate of thickness t as shown in the figure 1.4. The total optical path between a and c initially for the propagation of light is $nt + bc$ where n is the index of refraction of the plate (the quantity we are interested in). When plate is rotated through an angle i, optical path is increased to $(ad)(n) + de$.

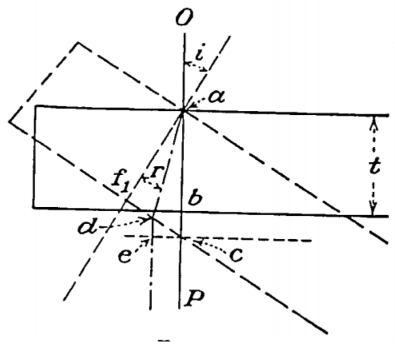

Figure 1.4: Diagram for path difference due to rotation of glass slide

Hence, total increase in optical path is:

$$\delta_1 - \delta_2 = 2((ad)n + de - nt - bc) = N\lambda$$

Where N is the number of fringes collapsed and λ is the wavelength of the light being used. δ_2 and δ_1 correspond to the path lengths for the cases of glass slide placed normally to the incoming light and rotated by an angle i respectively. Since the beam traverses the plate twice, the factor 2 is multiplied with the total path difference.

A simple geometrical analysis tells us:

$$ab = \frac{t}{cos(r)}$$

where r is the angle of refraction of the light beam. Additionally, we have:

$$de = dcsin(i) = (fc - fd)sini = (t)(tan(i))(sin(i)) - (t)(tan(r))(sin(i))$$

$$bc = \frac{t}{cos(i)} - t$$

Substituting appropriately we have:

$$\delta_1 - \delta_2 = 2(\frac{nt}{cos(r)} + (t)(tan(i))(sin(i)) - (t)(tan(r))(sin(i)) - nt - \frac{t}{cos(i)} + t) = N\lambda$$

Using Snell's law, i.e. $sin(i) = nsin(r)$ we get:

$$n = \frac{(2t - N\lambda)(1 - cos(i))}{2t(1 - cos(i)) - N\lambda}$$

Use the above-mentioned formula to calculate the refractive index of the glass slide. Remember to take multiple readings for variable N, so you can calculate the refractive index with more confidence.

Experimental Setup

Apparatus

1. Laser source
2. Mirrors
3. Beam splitter
4. Screen
5. Holders and mounts for mirrors and beam splitter
6. Glass slide
7. Rotatable mount

Warnings

1. This experiment is **extremely** sensitive to small changes. Even placing a hand on the table results in a change in the interference pattern observed.
2. Ensure that all the mirrors are aligned as well as possible to ensure a clearly visible pattern.
3. Be careful while rotating the micrometer because even slight tremble in hands causes a large movement in the interference pattern. You can use foam to smoothen the movement of the micrometer and add a buffer between your hands and the device to prevent the vibrations.

Procedure

Part A

- Set up the interferometer as shown in the figure 1.1 on the optical table with one fixed and one translatable mirror.
- Place the beam splitter at 45° angle, the lasers and the mirrors can be adjusted so that the reflected and transmitted beams hit the centres of the mirrors.
- Align until you see a discernible interference pattern on the screen.
- For alignment, remove the beam widener and first overlap the beams this way and then do minor adjustments with the beam widener attached to get a stable pattern on the screen.
- The wavelength of the laser light source can be determined if the translatable mirror is moved in a controlled manner by the micrometer screw of the translational stage and the corresponding number of fringes moved are counted, using the formula given in the equation 1.3.

Part B

- The theory and setup is pretty much the same for this part as the previous one, with the only difference being that a glass slide has been added between the beam splitter and the movable mirror in one of the arms of the interferometer.

- The introduction of the glass slide changes the path difference. If the thickness of the glass plate is t and the refractive index is n, then the path length changes by $nt - t$.
- If the plate is rotated through a small measured angle, the path of the light will be changed as the length of the glass in the path will increase and therefore the number of wavelengths in that path will increase.
- Count the number of fringes moved (collapsing or emerging) corresponding to this change.