MICHELSON’S INTERFEROMETER

Objectives:

1. Alignment of Michelson’s Interferometer using He-Ne laser to observe concentric circular fringes
2. Measurement of the wavelength of He-Ne Laser and Na lamp using circular fringes
3. Study of fringes of equal inclination and equal thickness using Na lamp

Introduction

Instruments based upon the principle of interference are called interferometers. These are basic optical tools used to precisely measure wavelength, distance, index of refraction, and temporal coherence of optical beams, etc. Amplitude-splitting interferometers were devised by Albert Michelson in 1890, the first American physicist to receive the Nobel Prize (1907 for work in optics). Michelson and Morley used this interferometer in their celebrated series of experiments designed to demonstrate the existence of the ether. It is still an important instrument in today's laboratories and it is being widely used as an instrument for measuring the wavelength of an unknown light source, to measure extremely small distance and for investigating optical media.

Construction:

Construction of Michelson interferometer is shown in Fig. 1. It consists of two highly polished mirrors M_1 and M_2. Two glass plates beam splitter (BS) and compensatory glass plate (CP), are placed parallel to each other between the mirrors at an angle of 45^0. The rear side of glass plate BS is semi-silvered such that the light from a source is equally reflected and transmitted by it. In this way division of

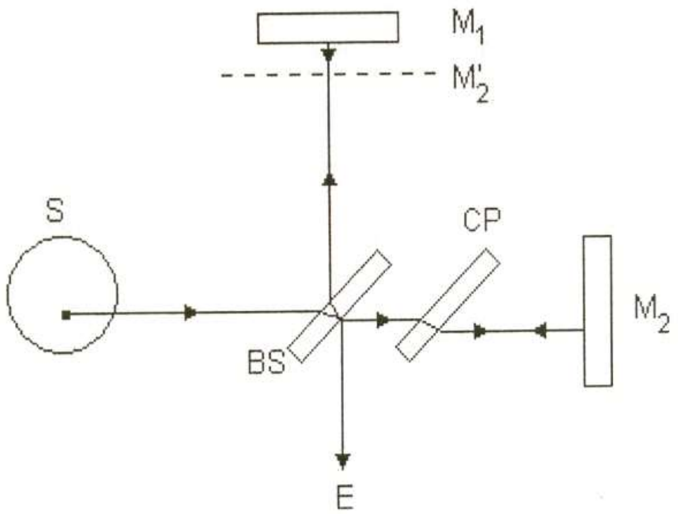

Fig. 1 : Construction of Michelson’s Interferometer

amplitude takes place. From a broad source, let a monochromatic light of wavelength λ fall on BS. Half of the light falling on BS is reflected towards the mirror M_1 and the other half is transmitted towards mirror M_2. Hence BS is known as a beam splitter. In case of sources which are not monochromatic, the glass plate CP is inserted between BS and M_2. The role of CP is explained further in the following paragraph. After splitting, the two rays are reflected back by the mirrors M_1 and M_2 and return to the plate BS. The ray reflected from M_1 is transmitted through BS and the ray reflected from M_2 is reflected again by BS. The two rays coming from the two mirrors interfere and fringes are observed on a screen (for laser) or by naked eye (Na lamp) at E. Usually one of the mirrors is mounted on a translation stage so that it can be moved back and forth to observe the change in fringes.

Optical path

The rays falling on mirrors M_1 and M_2 are derived from the same source originally incident on plate BS (see Fig. 1). The wave reflected from M_1 and entering the eye crosses BS twice. However the path of the other wave falling on the mirror M_2, in the absence of compensating plate CP, travels totally in air. Thus an extra optical path $2(\mu -1)t$ is introduced where, 't' is the thickness of the plate and 'μ' is the refractive index of the BS plate for the monochromatic light used. Presence of CP is not essential if fringes are produced with monochromatic light. But it produces a serious problem when white light is used. Thus, it becomes necessary to compensate for the extra optical path $2(\mu -1)t$ for all wavelengths. This is done by introducing another glass plate CP of the same thickness and refractive index as that of BS parallel to it. Thus, the two waves will interfere constructively or destructively as per the following conditions of path difference, Δ:

$$\Delta = 2n\lambda/2 = n\lambda \qquad \text{(for maxima, n is an integer)}$$

$$\Delta = (2n+1)\lambda/2 \qquad \text{(for minima, n is an integer)}$$

Types of fringes:

Path difference between the two rays can be varied by moving M_1. Mirror M_1 and the virtual image of mirror M_2 act as the two surfaces of an air film. The fringes formed in Michelson interferometer may be circular, curved or straight depending upon the nature of the air film.

Concentric circular fringes (fringes of equal inclination):

Concentric circular fringes are obtained when the air film is parallel as shown in Fig. 2. $\mathbf{M_2}'$ is the virtual image of $\mathbf{M_2}$ and it is parallel to $\mathbf{M_1}$. For simplicity, light source **L** is at the observer's position. $\mathbf{L_1}$ and $\mathbf{L_2}$ are the virtual images of **L** formed by $\mathbf{M_1}$ and $\mathbf{M_2}'$, and are coherent. Let d be the distance between M_1 and M_2', therefore the distance between $\mathbf{L_1}$ and $\mathbf{L_2}$ is $2d$. Let θ be the angle between the incident beam originated at P and the reflected beams from $\mathbf{M_1}$ and $\mathbf{M_2}'$. Then the path difference between the light beams from points P'and P" is 2d cosθ. A maximum (bright fringe) will be formed when $2d\cos\theta = n\lambda$. For a fixed value of n, λ and d, the value of θ is a constant, and the contour of the maximum 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 the fringes are known as **fringes of equal inclination**.

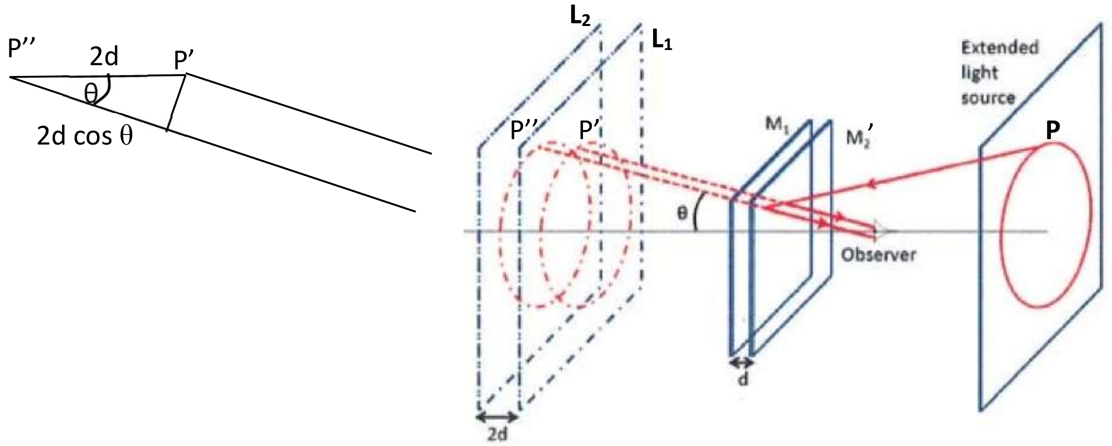

Fig. 2: Formation of circular fringes

Curved fringes (fringes of equal thickness):

When $\mathbf{M_1}$ and virtual image $\mathbf{M_2}'$ are inclined to each other, the film enclosed is wedge shaped. Then curved fringes can be observed as shown in Fig. 3. These are also known as fringes of equal thickness.

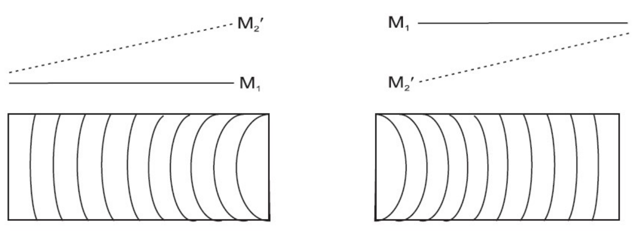

Fig. 3: Formation of curved fringes

Straight line fringes:

When $\mathbf{M_1}$ and virtual image $\mathbf{M_2}'$ intersect, straight line fringes are obtained around the point of intersection (see Fig. 4). The path

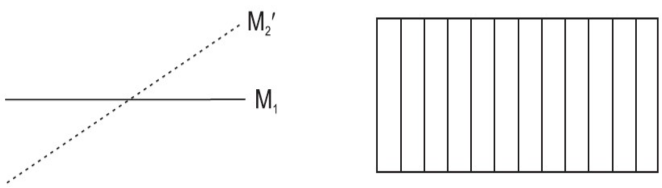

Fig. 4: Formation of straight line fringes

difference along the line of intersection is zero and therefore, is same for all the wavelengths. When a source of white light is used we get a central achromatic bright fringe. On either side of the central fringe, a few coloured straight fringes are observed.

Determination of λ from circular fringes:

Circular fringes are used to determine the wavelength of the source of light. For a given separation 'd' between the mirrors M_1 and M_2 and normal incidence ($\theta=0$), the path difference is given as $2d = n\lambda$.

If one mirror is moved by a distance Δd and N number of rings appear/disappear at the center, then the path difference after moving the mirror is given as

$$2(d+ \Delta d) = (n+N)\lambda$$

Hence,

$$\boldsymbol{\lambda = 2(\Delta d)/N}$$

Experimental set up:

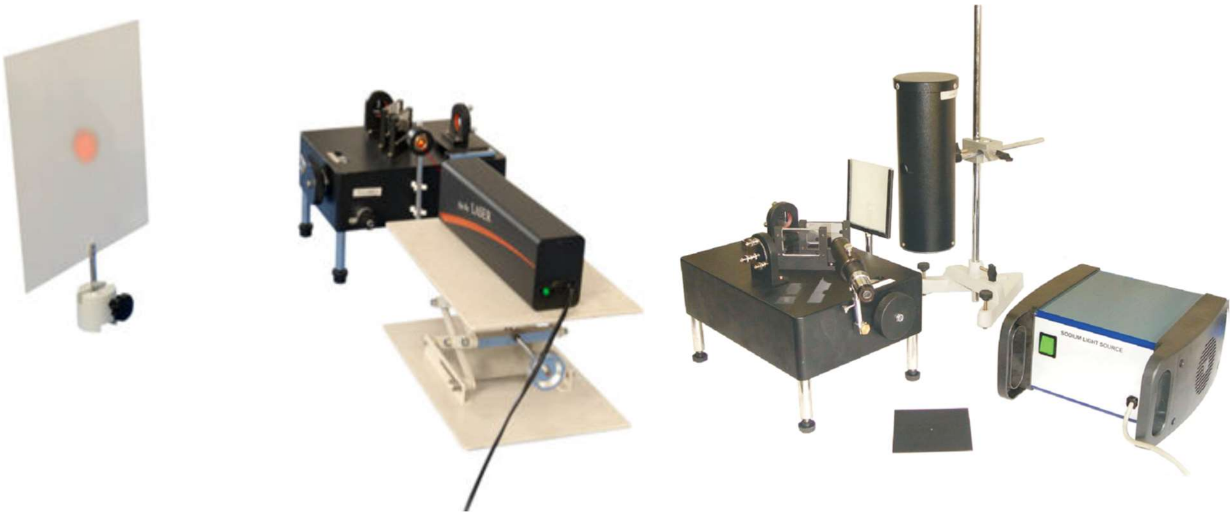

Fig. 5: (a) Set up with laser as source (b) Set up with Na lamp as source

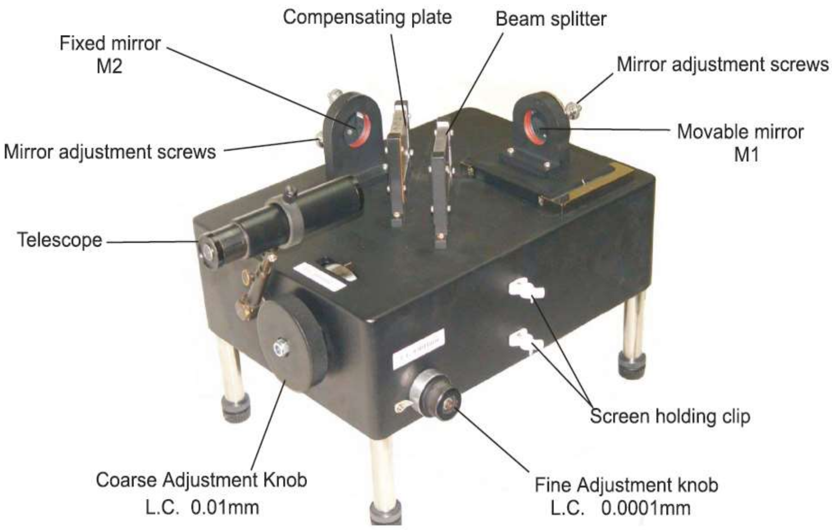

Fig. 6: Schematics of Michelson Interferometer

Procedure:

The complete experimental set up is shown in Fig. 5 (a) and (b) with laser and Na lamp as the source, respectively.

(I) Observation of circular fringes using He-Ne laser as the light source

1. Set the Michelson Interferometer on the table with coarse adjustable knob pointing towards you.
2. Set the lab jack in front of the microscopic objective holder and set the height using lifting knob.
3. Place the He-Ne Laser source on lab jack, pointing the source towards the centre of fixed mirror.
4. Turn the laser on and adjust the laser beam height using lab jack lifting knob until the beam is approximately parallel with the top of the interferometer and strikes the mirror at the center.
5. Set the viewing screen opposite of the adjustable mirror M_1. Note that the viewing screen should be placed at 1-2meter from the adjustable mirror to get better resolution.
6. To get circular fringes, M_1 should be exactly perpendicular to M_2. In this position, Michelson interferometer is said to be in normal adjustment. The setting needs that the plane of BS exactly bisects the angle (45°) between the two mirrors.
7. Using coarse adjustment knob makes the distance of M_1 and M_2 from BS nearly equal.
8. When the laser beam is passing through the beam splitter (BS) at 45° and observed in the direction of M_2, four spots of the He-Ne Laser beam are seen on the viewing screen; two of these are faint and two are intense. The faint spots are due to reflection from the un-silvered surface of the BS and then from M_1 and M_2. The intense spots are due to reflection from the silvered surface of the BS and M_1 and M_2. (Note: two spots of the He-Ne laser beam can also be seen on the viewing screen other than the four spots, which are ignorable because these two spots are formed by reflections from the compensating plate).
9. The tilting screws at the back of M_1 and M_2 are adjusted to obtain only two images. This happens only when the mirrors M_1 and M_2 are exactly perpendicular to each other.
10. Now place the beam expander in the objective holder in front of the laser and adjust its height to get circular fringes. Make fine adjustments of mirrors M_1 and M_2 using the top tilting screws to observe clear fringes on the viewing screen.

(II) Determination of wavelength of He-Ne laser light source

1. Obtain the circular fringes as already explained.

2. Move the mirror M_1 using the fine adjustment knob. The fringes appear or disappear in the field of view. (Always move the knob in one direction for precise measurement.)

3. Note down the reading of coarse adjustment knob. Let it be ‘p’. Multiply this reading with least count 0.01mm. Note the reading of fine adjustment knob. Let it be ‘q’. Multiply this reading with least count 0.0001mm. Now add the above two readings of coarse and fine adjustment knobs. Let it be d_1.

5. Rotate the fine adjustment knob to count the number of fringes appearing or disappearing. Let it be N.

6. Note the observations as already explained in step 3. Let it be d_2.

7. Subtract d_1 from d_2 to get the value of ‘Δd’ for ‘N’ fringes

8. Repeat the above steps from 3-7 for different values of d_1 and d_2.

9. Use the formula to calculate the value of λ in each case and then find the mean λ.

(III) Observation of circular fringes using Na lamp as the light source

1. Perform steps 1-10 from procedure I.
2. Replace the laser with the Na lamp and switch it on.
3. Put a ground glass screen in front of the lamp to reduce its brightness.
4. A fringe pattern should appear on the screen and only fine adjustments of the movable mirror should be necessary. You can also view the pattern with the naked eye or by attaching a telescope near the coarse adjustment knob.

(IV) Determination of wavelength of Na lamp

Follow the same procedure as described in (II).

(V) Fringes of equal inclination

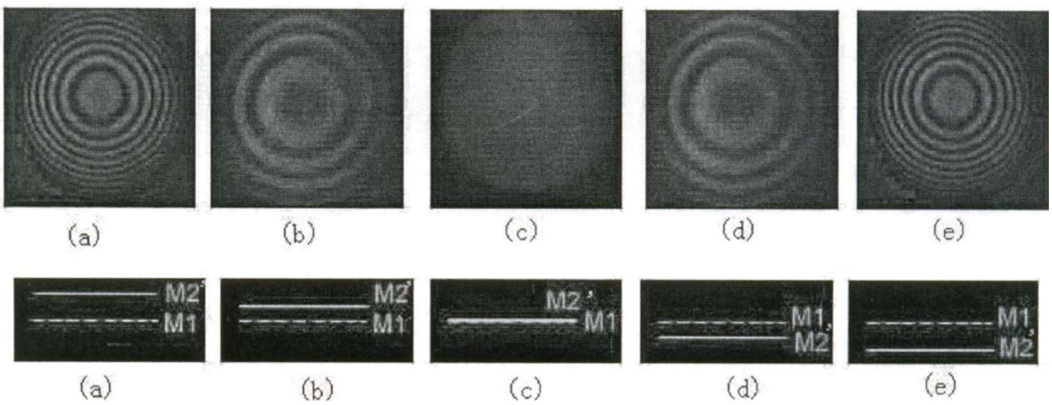

Fig. 7: Fringes of equal inclination

1. Using He-Ne laser as light source reproduce circular fringes similar to Fig. 7(a). Orientation of M_1 and M_2' is shown in the bottom panel corresponding to each set of fringes in Fig.7 (a-e).
2. Adjust the coarse micrometer such that images (a) to (e) are viewed in succession.
3. Set the fine micrometer to the middle of the scale.
4. Readjust the coarse micrometer as close as possible to image Fig. 7(c). you may need to realign the mirrors with help of the tilting screws to obtain the condition in Fig. 7 (c).
5. Use the fine micrometer to produce fringes of equal inclination.
6. Take pictures of the fringes in a similar way shown in Fig. 7.

(VI) Fringes of equal thickness

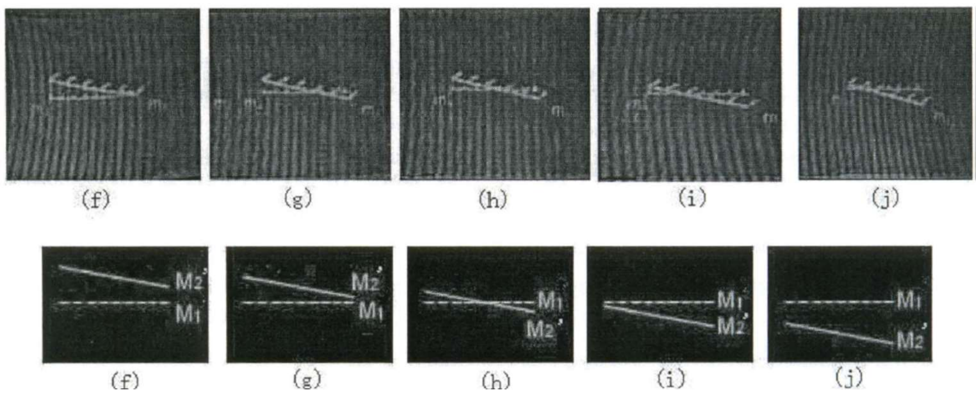

Fig. 8: Fringes of equal thickness

1. Using He-Ne laser as light source turn the fine micrometer to move the movable mirror in a direction such that only a few interference circular fringes are visible.
2. Adjust the movable mirror a little such that M_1 and M_2' form a wedge-shaped air film. In this condition, you will observe curved fringes as shown in Fig. 8f). The orientation of M_1 and M_2' is shown in the bottom panel corresponding to each set of fringes in Fig.8 (f-j).
3. Continue to turn the fine micrometer to make the curved fringes move toward their centre. Some straight fringes can be observed (if done very carefully) in succession as shown in Fig. 8 (h), when M_1 and M_2' intersect each other.
4. Take pictures of the fringes in each of the configurations as shown in Fig. 8(f-j).

Observations: (For He-Ne laser/ Na lamp)

Sl. No..	N	d_1	p	q	$d_2 = p + q$ (mm)	$\Delta d = (d_2 - d_1)$ (mm)	λ (nm)	Mean λ (nm)

Results and Discussions

λ for He-Ne laser =

λ for Na lamp =

Literature values: λ for He-Ne laser = 632.8 nm

λ for Na lamp = 589.3 nm

Precautions:

1. When turning the fine adjustment knob to count fringes, always turn it one complete revolution before you start counting. This will almost entirely eliminate errors due to backlash in the fine adjustment knob.
2. Always turn the fine adjustment knob in one direction either clockwise or anti-clockwise.
3. Direct eye exposure to laser should be avoided.
4. Observing laser interference fringes by reflecting mirror is prohibited.
5. Avoid touching any of the optics with bare hand.

References:

1. Supplier manual
2. Fundamentals of Optics, Jenkins & White