5. Operation of Experimental Examples

5.1 Interference Fringe Observation

He-Ne laser as the light source

> **Warning:**
> a) Direct eye exposure to laser should be avoided.
> b) DO NOT observe the laser interference fringes by using the reflecting mirror.
> c) All experiments should be conducted under low-light conditions for better observation of interference phenomena.

1) Place the laser mount with a He-Ne laser mounted in the mounting hole on the side stage and turn on the laser power.
2) Let the beam expander enter the optical path. Adjust the height of the laser tube to make the beam hit the center of the beam expander. Then turn the beam expander by 90° so it is out of the optical path.
3) Observe the beam spot on the beam splitter; it should be approximately in the middle of the beam splitter. Also observe the beam spots on both mirrors. Adjust the laser tube to make the beam spots on beam splitter and mirrors at the same height.

   Note: The alignment aperture can be used to assist the procedure by placing the alignment aperture in the two holes (15) alternatively (**Note**: there are two mounting holes numbered as 15). This may involve tilting the tube, so remember to re-adjust the height each time when tilting occurs.

4) Place the ground glass screen into the corresponding holding socket (14). A group of beam spots should be seen on the screen, which are reflected from the two mirrors. Block one mirror to find which spot is reflected from the other mirror. There are also other spots on the screen with less brightness due to multiple reflections from the beam splitter.

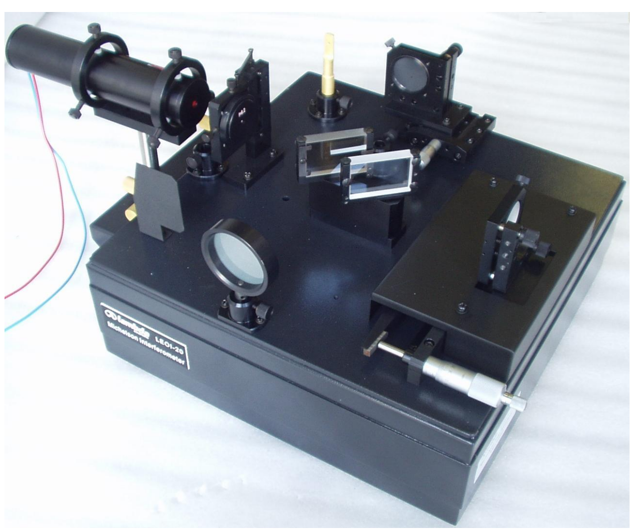


Figure 3 Michelson interferometer with He-Ne laser as light source

5) If the brightest two spots are not overlapping, adjust the tilt screws behind either mirror (or both mirrors) until the two brightest spots coincide with each other at the center of the ground glass screen.

6) Turn the beam expander by 90°, so it is in the optical path. Adjust the translational screws (*x* axis and *y* axis) of the beam expander; let the expanded beam hit the central areas of both mirrors.

   If the adjustment range of the translational screws is not enough to bring the beam to the center of a mirror, adjust the height/tilt of the laser tube instead. In the latter case, it needs to turn the beam expander by 90° to be out of the optical path again to check if the two brightest spots still overlap on the screen. If not, adjust tilt screws of mirrors to overlap them.

   At this moment, the fringe pattern can be observed on the ground glass screen. Finely adjust tilt screws to bring fringe center to pattern center.

If the observed fringes are not circular, or they are smaller than you may expect, then adjust the preset micrometer to 'zoom' in or out to get a better view. If no fringes are observed, then repeat the instructions from the beginning; otherwise contact sales@lambdasys.com for technical support.

Sodium lamp as the light source

Figure 4 Michelson interferometer with Sodium lamp as light source

1) Remove the He-Ne laser and turn beam expander by 90° to be out of the optical path. Place Sodium light source in the mounting hole.

2) Remove the observation screen (ground glass screen), view interference pattern directly by looking toward Mirror 1 along the optical path. If needed, adjust the height of the

light source, so that the Sodium light strikes at the center of the mirrors. Generally, interference fringes can be observed.

Note: If no fringes are observed, it means that the interference light path has changed due to vibration when replacing the light source. To retrieve the fringes, the following procedure should be taken.

3) Place the alignment aperture in the hole (15) (the one in front of the beam splitter) and adjust the tilt of one mirror until the two images of the pinhole coincide with each other. (**Note**: Instead of using the alignment aperture, the pinhole plate may also be used in this procedure.)
4) Remove the alignment aperture and interference fringes should be observed by directly viewing toward mirror 1. Using the ground glass screen is optional in this experiment, but if in use, it should be inserted between the light source and the beam splitter (as seen in Fig. 2, Socket 16).

5.2 Equal-Inclination Interference

Now let's study a different kind of fringes produced by a Michelson interferometer. As shown in Figure 5**,** $\mathbf{M_2}$**'** is the virtual image of mirror $\mathbf{M_2}$**.** In the observer's field of view, it seems that the two light beams were reflected from mirrors $\mathbf{M_1}$ and $\mathbf{M_2}$**'** and the interference pattern were produced by a thin air film between $\mathbf{M_1}$ and $\mathbf{M_2}$**'**.

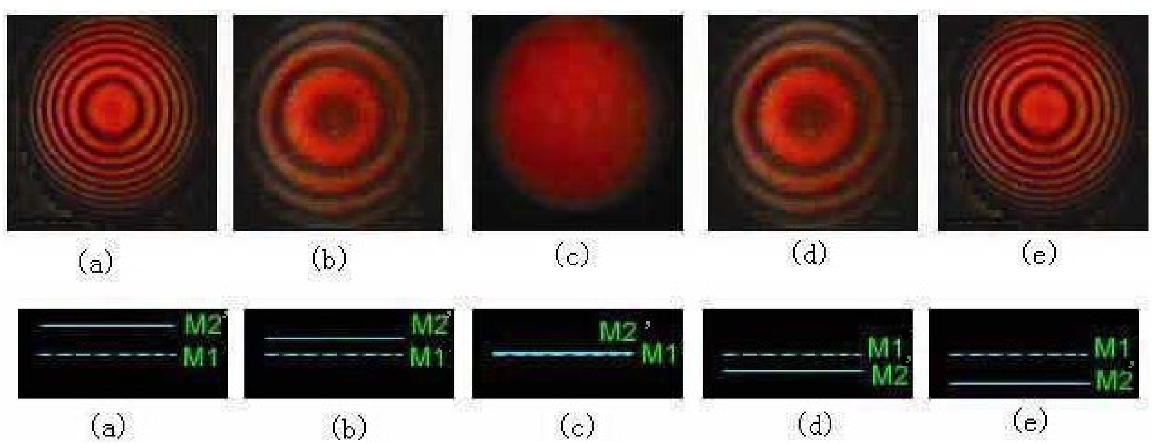


Figure 5 Illustration of equal-inclination interference

<u>He-Ne laser as the light source</u>

1) Re-produce the interference image as per 5.1, which should be similar to (a).
2) Adjust the preset micrometer so that images (a) to (e) are viewed in succession.
3) Set the fine micrometer to the middle of the scale (between 10 mm to15 mm).
4) Re-adjust the preset micrometer as closely as possible to reproduce image (c).
5) Use the fine micrometer to produce fringes of equal inclination.

5.3 Equal-Thickness Interference

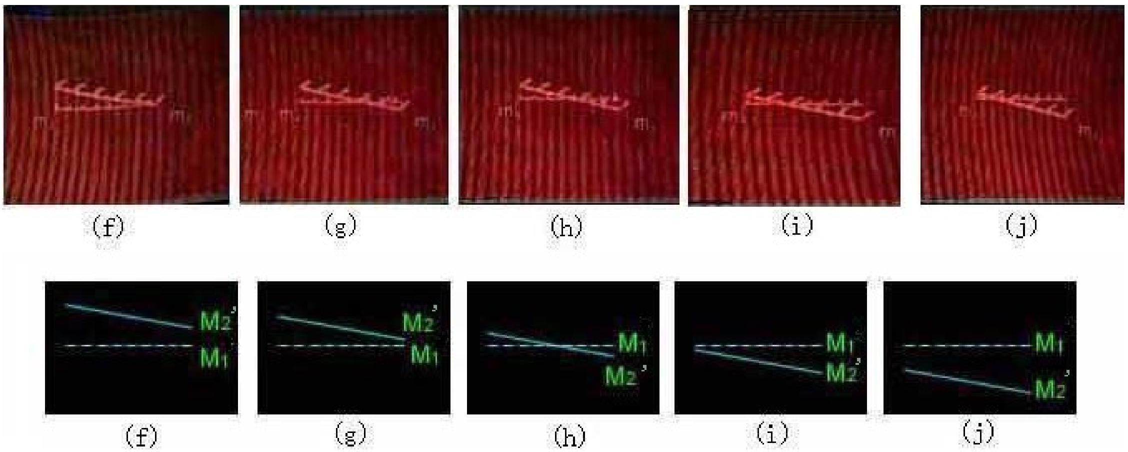


Figure 6 Fringes of equal thickness

Adjust the screws at the back of $\mathbf{M_2}$. If $\mathbf{M_1}$ and $\mathbf{M_2'}$ are tilted with a very small angle with each other, the fringes of equal-thickness interference can be observed on the screen.

He-Ne laser as the light source

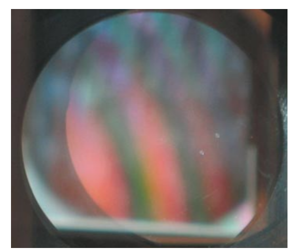
1) Install the He-Ne laser and turn the beam expander by 90° to be out of the optical path. Set the fine micrometer to the middle of the scale (between 10 mm to15 mm).
2) Adjust the laser and one mirror to get interference pattern on the ground glass screen.
3) Turn the preset micrometer in the direction which interference rings collapse at the center, and then the fringes expand. Stop when there are only a few fringes on the screen.
4) Turn the fine micrometer to move mirror 2 in the direction which interference rings collapse at the center, until there are only two or three rings left.
5) Adjust mirror 2 slightly. If the image of mirror M_2' is tilted relative to mirror M_1, interference stripes should be observed.
6) Continue to turn the fine micrometer to make the curved fringes move toward their center. Some straight bands will appear in succession. Those are the fringes of equal-thickness interference.

5.4 White-Light Interference Fringes

Because white light has a short coherence length, interference fringes from white light can only be observed when the optical-path difference is close to zero. Compared to the interference pattern created by a laser or a Sodium lamp, white light interference is much more difficult to produce. With the help of a specially designed Sodium-Tungsten lamp, zero path difference can be easily obtained for the observation of white-light interference.

Figure 7 Michelson interferometer with Sodium-Tungsten lamp as light source

1) After achieving equal-inclination interference (5.2), replace the laser with a Sodium-Tungsten lamp and turn the beam expander by 90° to be out of the optical path. Remove the ground glass screen (observation screen), and directly view pattern by looking toward Mirror 1 along the optical path.
2) Adjust the height of the light source until the yellow Sodium light and white Tungsten light illuminate the upper and lower half of the viewing field, respectively. Make sure that the visible Sodium fringes have good contrast and wide-spacing. Interference fringes of Sodium doublet may help locate the point of zero path difference. Also, the brightness of the white light source are adjustable, adjust its brightness as needed.



Note: If no fringes are observed, it means that the interference light path has changed due to vibration when replacing the light source. To retrieve the fringes, the following procedure should be taken.

3) Place the alignment aperture in the hole (15) (the one in front of the beam splitter) and adjust the tilt of one mirror until the two images of the pinhole coincide with each other. (**Note**: Instead of using the alignment aperture, the pinhole plate may also be used in this procedure.) Now interference fringes should be seen by directly viewing toward mirrors.
4) To search for white light fringes, turn the fine micrometer slowly to maintain the yellow fringes in the field of view. Otherwise, the condition of zero path difference and hence the production of white light fringes might be missed if the fine micrometer were turned too fast.
5) This way color fringes will continue to appear, and at a moment, an interference fringe pattern with a dark center will be observed. That is the white-light interference at the position of zero light-path difference.
6) To observe the white-light interference fringe clearly, the Sodium lamp should be turned off and the ground glass screen should be put in socket 16.

5.5 Measurement of Wavelengths of Sodium D-lines

Figure 8 Michelson interferometer with Sodium-Tungsten lamp as light source

1) Place the Sodium-Tungsten lamp on the side-stage and warm it up for about 5 minutes.
2) Adjust the interferometer to produce circular fringes in the field of view.
3) At the position with a clear equal-inclination fringes, record the reading d_0 of the fine micrometer.
4) Count the number of fringes that expand (or collpase) in the center of the field of view while turning the fine micrometer slowly. After counting 50 fringes, record the micrometer reading again.
5) Continue the above process through 250 fringes, and record the micrometer reading after each set of 50 fringes has been counted. 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 fringes counted. On the other hand, the wavelength of the source can be determined by

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

Alternatively, one can plot Δd vs ΔN, and conduct linear curve-fitting to the data, the fitted slope is $\lambda/2$.

Notice:

a) Always turn the micrometer knob in one direction to eliminate backlash errors.
b) Set the micrometer screw somewhere near the middle of its travel. In this position, the relationship between the micrometer reading and the mirror movement is nearly linear.
c) Turn the micrometer a full turn before counting fringes to eliminate backlash errors.

5.6 Measurement of Wavelength Separation of Sodium D-lines

The Michelson interferometer can also be used for measurement of the wavelength separation of the Sodium D-lines. The yellow Sodium doublet includes two kinds of monochromatic light with a small wavelength separation between them. Therefore, when a Sodium lamp is used as the light source in a Michelson interferometer, the interference fringes produced by two yellow lines will appear periodically (clear and blurry) as the mirror is moved continuously. The wavelength difference of the yellow sodium doublet lines is given by

$$\Delta\lambda = \frac{\bar{\lambda}^2}{2\Delta d}$$

Where $\bar{\lambda}$ is the averaged wavelength of the two lines through the result of last experiment, Δd is the thickness of the air membrane between mirrors $\mathbf{M_1}$ and $\mathbf{M_2}$**'**.

1) Adjust the interferometer to obtain a clear, wide-spaced interference pattern of Sodium doublet. Slowly turn the fine micrometer till all the fringes disappear. Record the reading d_1 of the micrometer;
2) Continue to turn the micrometer in the same direction and new interference pattern appears. Record the reading d_2 where the interference pattern vanishes again;
3) Repeat this process in different places near zero path difference point to get an average value of $\Delta d = |d_1 - d_2|$.

5.7 Measurement of Refractive Index of Air

In Michelson interferometer mode, if an air chamber is placed in the light path of $\mathbf{M_1}$ and then the air density in the chamber is altered by deflating or pumping the air in the chamber, the optical-path length will change by δ. Accordingly, a certain number of interference fringes will pass through the viewing point.

$$\delta = 2\Delta n l = N\lambda$$

Therefore,

$$\Delta n = N\lambda / 2l$$

Where, l is the length of the air chamber, λ is the wavelength of the light source, N is the number of fringes counted to pass through the viewing point.

The refractive index of air is dependent upon its temperature and pressure. If n is near unity, then n-1 is directly proportional to density ρ of the gas. For ideal gas:

$$\frac{\rho}{\rho_0} = \frac{n-1}{n_0-1}$$

If T is the absolute temperature, P is the pressure. Then,

$$\frac{\rho}{\rho_0} = \frac{PT_0}{P_0T}$$

Thus,

$$\frac{PT_0}{P_0T} = \frac{n-1}{n_0-1}$$

If the temperature is constant, then

$$\Delta n = \frac{(n_0-1)}{P_0}\Delta P$$

Because $\Delta n = N\lambda/2l$, then

$$\frac{(n_0-1)}{P_0}\Delta P = N\lambda/2l$$

Therefore

$$n_0 = 1 + \frac{N\lambda}{2l} \times \frac{P_0}{\Delta P}$$

Figure 9 Michelson interferometer with air chamber in optical path

1) Align the interferometer.
2) Adjust the fine mirror $\mathbf{M_2}$ 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 holding socket (for 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 reading 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,

$$n_0 = 1 + \frac{N\lambda}{2l} \times \frac{P_0}{\Delta P}$$

where P_0 is the atmospheric pressure (101.325 kPa); l=80 mm.

Note: This experiment should be conducted several times to get an averaged result.

Notice: To protect the gauge, the reading of the gauge should not be over 40 kpa