5. Operation of Experimental Examples

5.1 Michelson Interferometer

5.1.1 Interference Fringe Observation

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

Warning:
a) Direct eye exposure to laser should be avoided.
b) <u>DO NOT</u> observe the laser interference fringes using a 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 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 the alignment aperture at two mounting holes on base platform, alternatively.

   Note: This may involve tilting the laser tube and so remember to re-adjust the height each time tilting occurs. The aligned laser beam should pass the alignment aperture placed at both locations of the path.
3) Place beam expander in front of the He-Ne laser. Adjust the beam expander to make the expanded beam hit the center of both fixed and movable mirrors.
4) Push the 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 Figure 3. 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 brightness due to multiple reflections. Align the fixed mirror until the brightest beam spot is seen on the center of the screen.

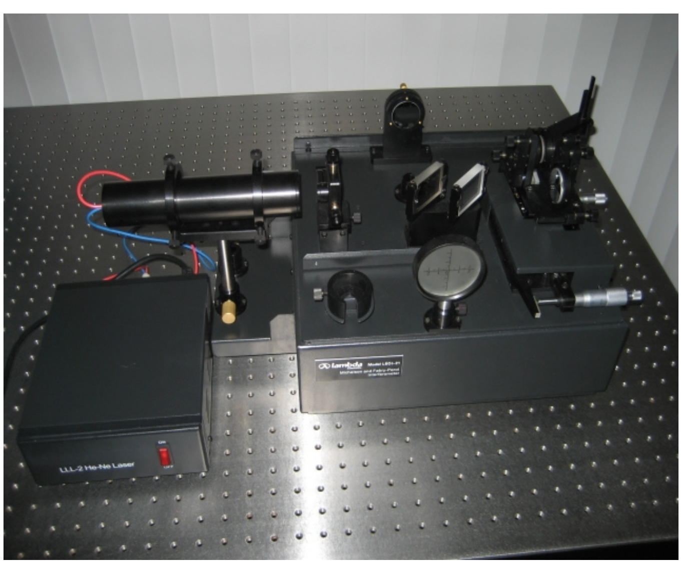


Figure 4 Michelson interferometer with He-Ne laser as light source

6) Remove the cards and observe the white screen. Two bright spots should appear (and less bright multiple reflections). Adjust the movable mirror until the two bright spots coincide with each other at the center of the 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. Adjust the tilting angles of the fixed mirror to move the spot onto the movable mirror.

If the observed fringes are not circular, or they are smaller than you may expect, then adjust the coarse 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

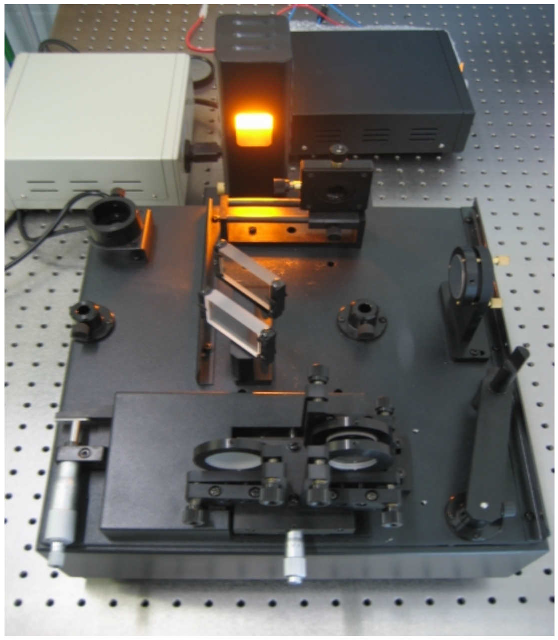


Figure 5 Michelson interferometer with Sodium lamp as light source

1) Remove the He-Ne laser and beam expander. Place Sodium lamp in the mounting hole.
2) Remove the ground glass screen as the observation screen. Adjust the height of the lamp, so that the Sodium light strikes at the center of the observation mirror. Generally, interference fringes can be observed from the reflected light (viewing through the beam splitter towards the fixed mirror).

   Note: If fringes are not observed, it means that the interference light path has changed due to vibration when replacing the light source. To retrieve the fringes, the following processes should be taken.

3) Place the alignment aperture in front of the lamp and adjust the movable mirror until the two images of the aperture coincide with each other.
4) Remove the alignment aperture and interference fringes should be observed.

5.1.2 Equal-Inclination Interference

Now let's study a different kind of fringes produced by a Michelson interferometer. As shown in Figure 6**,** $\mathbf{M_2'}$ is the virtual image of movable 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 $\mathbf{M_2'}$.

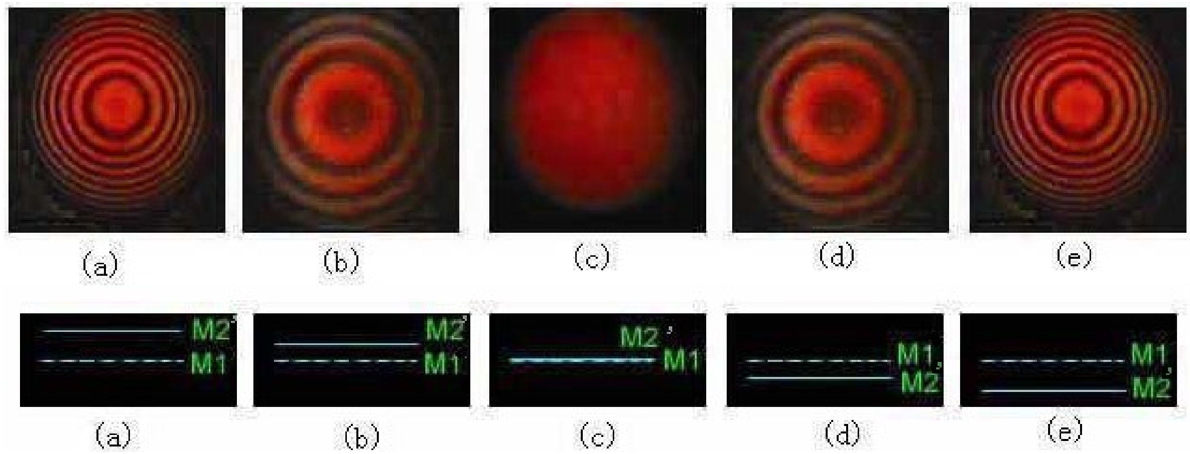


Figure 6 Illustration of equal-inclination interference

He-Ne laser as the light source

1) Re-produce the interference image as per 5.1.1, which should be similar to (a).
2) Adjust the coarse 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 coarse micrometer as closely as possible to reproduce image (c).
5) Use the fine micrometer to produce fringes of equal inclination.

5.1.3 Equal-Thickness Interference

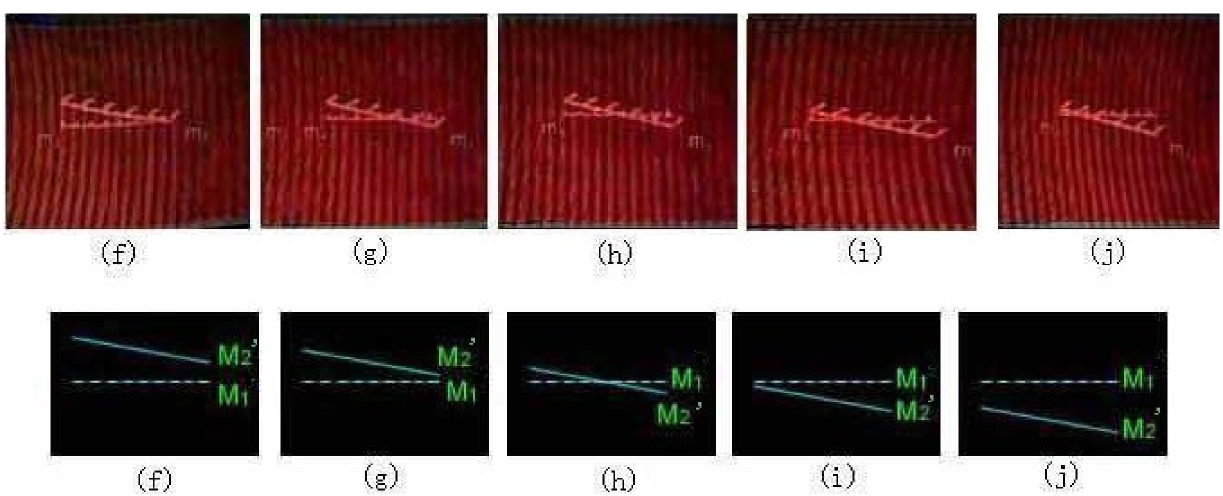


Figure 7 Fringes of equal thickness

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 remove the beam expander. Set the fine micrometer to the middle of the scale (between 10 mm to15 mm).
2) Adjust the laser and movable mirror to get interference pattern on the glass screen.
3) Turn the coarse 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 the movable mirror in the direction which interference rings collapse at the center, until there are only two or three rings left.
5) Adjust the movable mirror slightly. If the image of movable mirror M_2' is tilted relative to the fixed 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.

5.1.4 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.

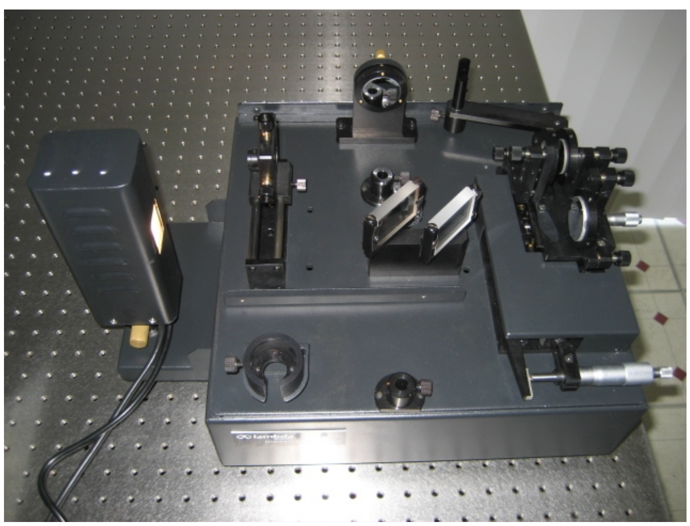


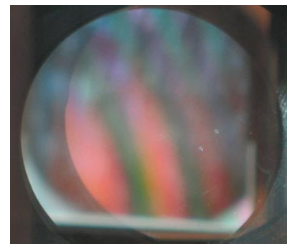
Figure 8 Michelson interferometer with Sodium-Tungsten lamp as light source

1) After achieving equal-inclination interference (5.1.2), replace the laser with a Sodium-Tungsten lamp and remove the beam expander. Interference fringes can be observed by viewing through the beam splitter towards the fixed mirror.
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.

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 processes should be taken.

3) Place the alignment aperture in front of the lamp and adjust the movable mirror until the two images of the aperture coincide with each other. Now interference fringes should be observed.



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 would 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 fringes clearly, the Sodium lamp should be turned off and the Tungsten lamp should be left on.

5.1.5 Measurement of Wavelengths of Sodium D-lines

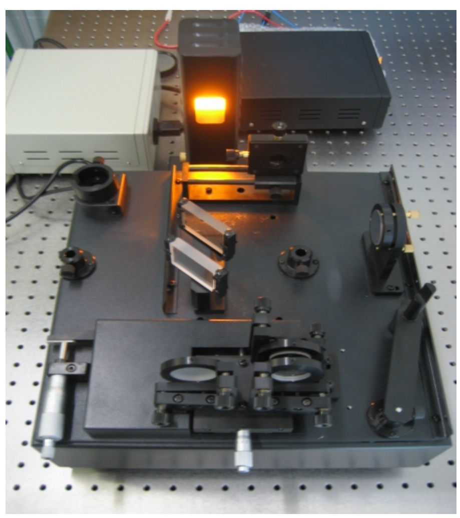


Figure 9 Michelson interferometer with Sodium-Tungsten lamp as light source

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) When clear equal-inclination fringes appear, 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 as the fine micrometer is turned slowly (using the provided manual counter). 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 $\lambda/2$.

Note:

a) Always turn the micrometer knob in one direction to avoid 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.

5.1.6 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 movable 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 $\Delta d = |d_1 - d_2|$.

5.1.7 Measurement of Refractive Index of Air

In Michelson interferometer mode, if an air chamber is placed in the light path of $\mathbf{M_2}$ 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,

$$\frac{\rho}{\rho_0} = \frac{PT_0}{P_0 T}$$

Thus,

$$\frac{PT_0}{P_0 T} = \frac{n-1}{n_0 - 1}$$

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 10 Michelson interferometer with air chamber in optical path

1) Align the interferometer.
2) Adjust the movable 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 holder (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 (using the provided manual counter). 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 carried out several times in order to get the average.

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

5.2 Fabry-Perot Interferometer

5.2.1 Multi-Beam Interference

1) Mount the He-Ne laser in the post holder for the Fabry-Perot interferometer. Align the laser beam with the aid of the alignment aperture to let the aligned laser beam pass the alignment aperture located at two locations of this path. Adjust the top and right screws behind the movable mirror to make the multiple beam spots shrink in all directions when observing behind the movable mirror. Now the two mirrors are near parallel. (**Note**: the FP mirrors were pre-aligned at factory, so major

realignment is unnecessary. **Avoid FP mirror contact or collision at all times!**)

2) Place a beam expander into the light path to create an area light source, so that the observer can observe a series of multi-beam interference rings as shown schematically in Figure 11.

If $\mathbf{G_1}$ and $\mathbf{G_2}$ are absolutely parallel to each other, the interference fringes on the ground glass screen will have a perfect circle shape (the ground glass screen should be mounted in the extension arm, behind the F-P movable mirror, and a dim environment may be needed to observe the interference fringes on the ground class screen).

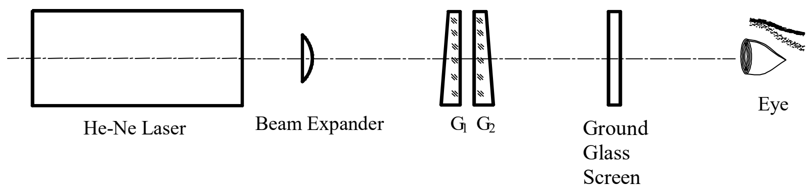


Figure 11 Diagram of the Fabry-Perot interferometer mode with ground glass screen mounted in extension arm

5.2.2 Measurement of Wavelength of He-Ne Laser

The interference fringes of F-P interferometer are clearer and thinner than those of Michelson interferometer. Thus, by using the same *fringe-counting* method with a F-P interferometer, the wavelength of a He-Ne laser can be measured more accurately.

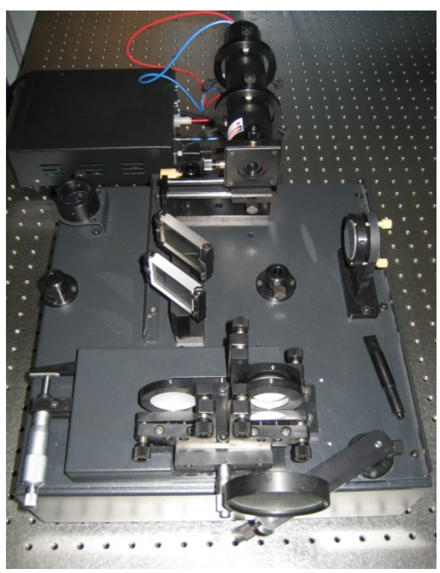


Figure 12 Fabry-Perot interferometer mode

1) Setup the F-P interferometer.

2) Adjust the interferometer carefully to produce clear circular fringes in the center of ground glass screen.

3) Record the reading d_0 of the fine micrometer.

4) Count the number of fringes that expand (or collapse) in the center of the ground glass screen as the micrometer is turned slowly (using the provided manual counter). After counting 50 fringes, record the micrometer reading again.

6) Calculate Δd. The actual mirror movement Δd is equal to $\Delta N\lambda/2$. Here λ is the wavelength of the source, ΔN is the number of fringes counted, and ΔN equals 50.

The moving distance is given by:

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

Thus,

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

7) To minimize any errors in counting the rings or recording the micrometer reading, steps 1- 6 should be repeated at least 3 times.

5.2.3 Observation of Interference of Sodium D-lines

If a low-pressure Sodium lamp is used as the light source in a F-P interferometer, two different sets of concentric interference fringes can be observed with a naked eye, as produced by the light emitted from a Sodium lamp with two different wavelengths. By turning the fine micrometer continuously, the two sets of interference fringes coincide at certain micrometer settings and separate at other settings.

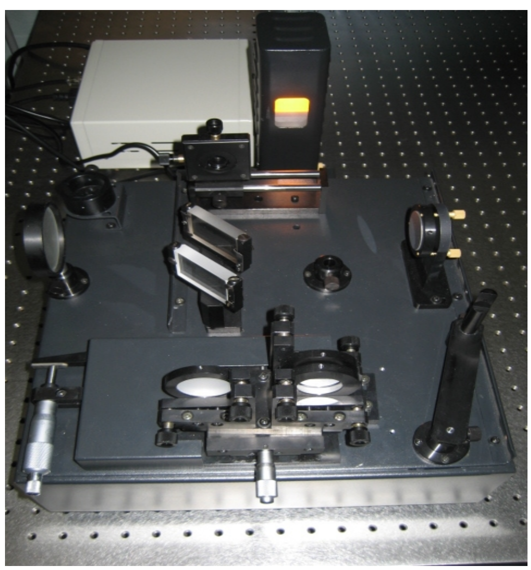


Figure 13 Fabry-Perot interferometer with Sodium lamp as light source

1) Setup the instrument in F-P mode. Use a Sodium lamp as the light source and turn it on.

2) Slowly move the movable mirror by adjusting the screws behind it till the two mirrors are very close to each other. The distance between them is about 1-2 mm. (Notice: Do not let them touch each other).
3) Adjust the movable mirror carefully till clear interference fringes are observed behind the F-P mirrors with a naked eye.
4) Slowly turn the fine micrometer to observe the Separating- Coinciding- Separating phenomenon of the interference fringes.