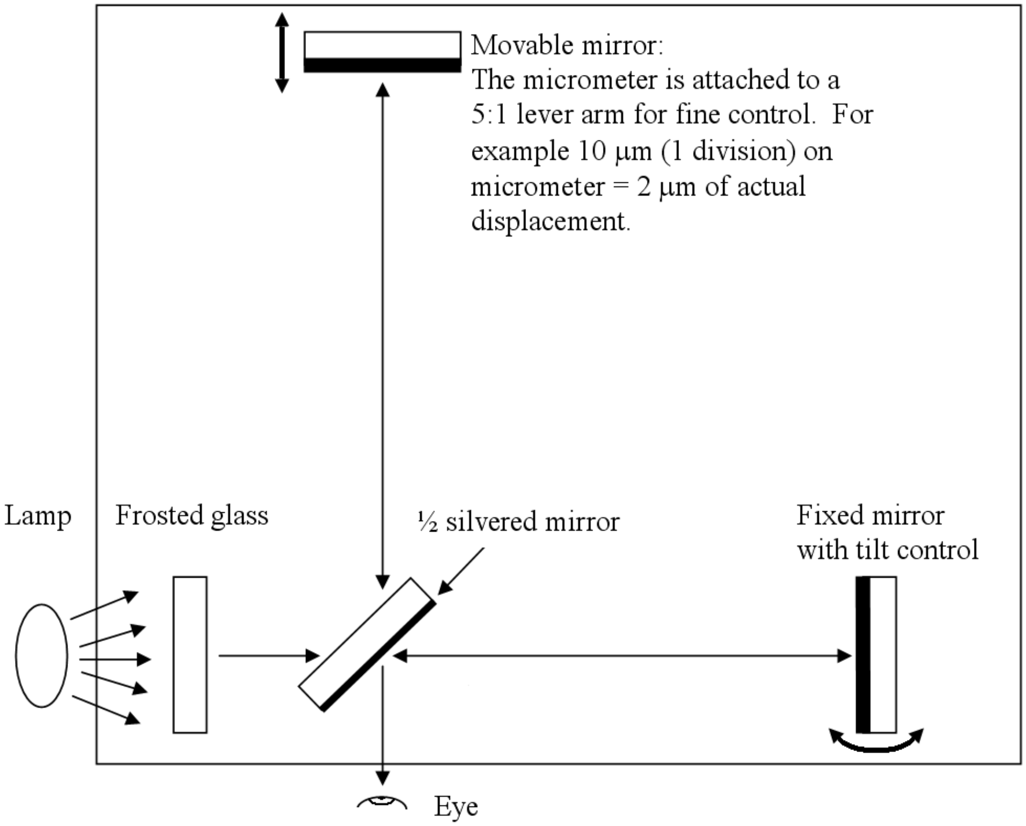
The Michelson Interferometer

In the last experiment, interference fringes were observed when two, nearly parallel reflecting surfaces were closely spaced. In a Michelson interferometer, a single beam of light is split into two beams by a half-silvered mirror. Each beam travels to a different mirror, which back-reflects the light through the half-silvered mirror and to the observer. The light that reaches the observer is the superposition of the two beams which thus interfere with one another.



For a narrow beam of light, if the two arms of the interferometer have exactly the same length, the optical path difference (OPD) between the two rays will be zero. Hence, if no phase difference is introduced by the reflection process, the two rays will be in-phase and a bright fringe appears. If you have an extended (large area) light source, you will see a radial pattern of light and dark fringes since the path length increases as the angle from the optical axis increases. If the position of the movable mirror shifts, the OPD changes and the fringe pattern moves. For light with a well-defined wavelength, each time the mirror is displaced by $\lambda/2$ the OPD increases or decreases by one wavelength. Hence the fringe pattern returns approximately to its original form. If the images of the two mirrors as seen by the observer are perfectly parallel, then a circular pattern results. Otherwise, the pattern will appear as nearly parallel lines.

In section D, you will investigate an optical beat pattern with a sodium lamp. An analog of this phenomenon occurs in acoustics when tuning a stringed instrument. If two strings are tuned to slightly different frequencies, the ear does not detect the pure tone of either string, but instead hears a tone equal to the average frequency, but with a pulsating amplitude.

Procedure:

A. With a Hg lamp as source (λ=546.1 nm—green line) adjust the controls of the interferometer to see which conditions give straight or circular fringes. As the OPD is varied, circular fringes may appear from or disappear toward the center. If they are appearing, moving outward from the center, then the OPD is increasing. If the fringes are moving toward the center, then the OPD is decreasing. Try to get the OPD close to zero. Near zero, the fringes will be very large and it will be difficult to tell whether they are moving inward or outward.

B. Now switch to a white light source and search for fringes. You will find that you can only see fringes if the OPD is less than 3λ. **Q1.** Why does the OPD have to be nearly zero in this case? For the parallel-line pattern, the fringe in the center corresponds to the angle where the OPD is exactly zero. **Q2.** Does the center fringe appear to be dark or bright? How can you explain this? Record the position of the micrometer at zero OPD for your interferometer.

C. Return to the Hg lamp to measure the wavelength of the green line. It is recommended that you adjust the appearance of the fringes to minimize eye strain. While slowly moving the mirror, count at least 50 fringes. From the distance the mirror translated, you can find the wavelength. **Q3.** What is the wavelength (in nm) and its uncertainty?

D. Now switch to the yellow Na lamp. The yellow line of the lamps is actually two very closely spaced lines at 589.0 and 589.6 nm. Near zero OPD you will observe clear fringes. As the OPD increases, the fringe pattern contrast decreases and becomes difficult to see. But the contrast eventually will increase again at larger OPD. You can go through several maxima and minima in this way. What you are seeing is the beat pattern between the two sodium lines. By measuring the wavelength and the separation of minima, calculate $\Delta\lambda$ using the formula

$$\frac{\Delta\lambda}{\lambda} = \frac{1}{n}$$

Here, n is the number of fringes in one period (minima to minima). This exercise requires more than 100 fringes. To maintain your sanity and eyesight, you may estimate the number of fringes. **Q4.** What is the wavelength difference of the two Na emission lines? What is the uncertainty in $\Delta\lambda$?