

Lab 6: Michelson Interferometer

1 Introduction

The Michelson interferometer has great historical significance, for it is the instrument that Michelson and Morely used to try and measure the Doppler shift of light travelling parallel to and perpendicular to the motion of earth through the ether. Furthermore, the basic layout continues to be used in many optical testing situations.

2 How it Works

The Michelson interferometer (see Fig. 1) is based on the use of some sort of beam splitter. This can either be a partially silvered mirror, or a cube beamsplitter (where a thin layer of a different refractive index is sandwiched between two prisms); the idea is that the beamsplitter transmits about half and reflects about half of the light incident upon it. One beam goes to a fixed mirror, and the other beam goes to a movable mirror. The beams are then re-combined on a viewing screen.

Question 1: Does it matter which mirror is movable and which is fixed? Why or why not?

Clearly the distances in Fig. 1 can be arranged so that there is destructive interference all across the viewing screen when the incident light beam is collimated to be parallel. In this case, there is light entering the interferometer, but no light on the screen.

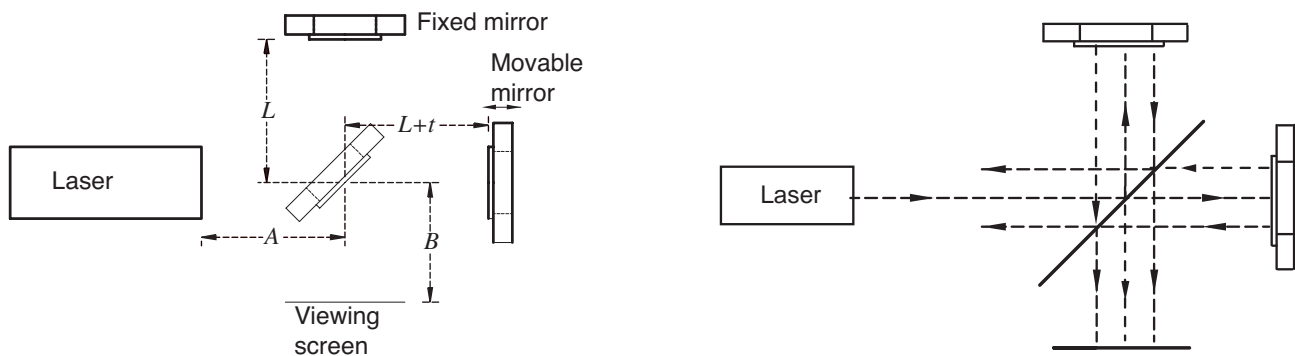


Figure 1: The Michelson interferometer. Left: equipment layout and distances. Right: ray paths. The offsets between ray paths are not real; they're just put in here for clarity.

Question 2: What happens to the energy? How can we conserve energy?

To figure out what's happening in the Michelson interferometer, let's consider rays which bounce off each of the mirrors separately yet which meet at a common point on the viewing screen and thereby interfere. This situation is sketched in Fig. 2 (next page). The path of the ray that bounces off the fixed mirror is given as

$$\ell_1 = \frac{A + L + L + B}{\cos(\theta_1)} \simeq (A + 2L + B) \left[1 + \frac{\theta_1^2}{2} \right], \quad (1)$$

where we have used the small angle approximation $\cos(\theta) \simeq 1 - \theta^2/2$, and similarly for ℓ_2 . The phase difference between waves travelling each of the paths is then given by

$$\begin{aligned}\Delta\varphi &= \frac{2\pi}{\lambda} \{\ell_2 - \ell_1\} \\ &\simeq \frac{2\pi}{\lambda} \left\{ 2t + 2t \frac{\theta_2^2}{2} - (A + L + L + B) \frac{\theta_2^2}{2} \left(\frac{t}{A + L} + \frac{t}{B + L} \right) \right\} \\ &\simeq \frac{2\pi}{\lambda} t \{2 - \theta_2^2\}.\end{aligned}\quad (2)$$

where t is the path length difference as shown on the left side of Fig. 1. The relationship between angle θ and fringe number m is

$$m = 2 \frac{t}{\lambda} (2 - \theta^2). \quad (3)$$

If we then write $m = m_0 - \Delta m$ and define $m_0 \equiv 4t/\lambda$, we find

$$\theta_m^2 = \Delta m \frac{\lambda}{2t} \quad (4)$$

as the angular position of the m^{th} fringe.

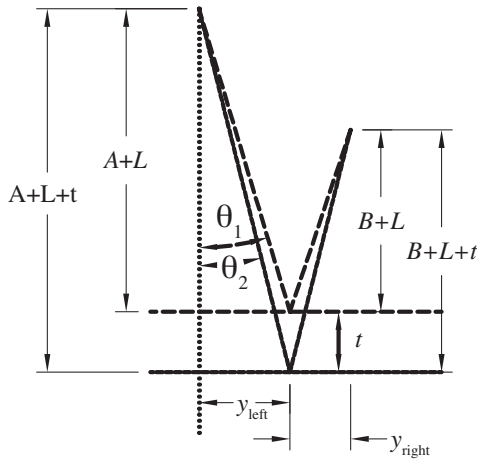


Figure 2: Schematic view of Michelson interferometer geometry.

3 The Experiment

Interferometers are highly sensitive optical instruments, capable of detecting minute changes in the optical path length of a beam of light. They provide one of the most accurate means of measuring position with an accuracy of fractions of a wavelength of the light used. We will use a Michelson interferometer to detect the position of a mirror, sense vibrations, measure fluctuations in air density, and compare the refractive indices of air and glass. We will also measure the wavelength of He-Ne laser light. For this experiment you will need:

- He-Ne laser
- Short optical bench

- Interferometer bench
- Interferometer kit
- Optics kit

The movable mirror is the one with the smallest mount, and the stationary mirror is the largest one (with alignment knobs on the back). The transparent window in the other mount is the beam-splitter. In addition to these, your interferometer kit contains a magnetic mount for the viewing screen in your optics kit. First, put your laser on the short bench, and level and adjust its height with the screw “legs.” Next, mount the elements as shown in Fig. 1, and check that the laser beam is at the right level to hit the mirrors and beam-splitter in their centers. Now, swing the beam splitter out of the way of the beam, and get the beam to hit the center of the movable mirror. Put the screen behind the movable mirror, and adjust the laser so that you only get one spot. Now the laser beam is perpendicular to the mirror.

Next, rotate the splitter back into the beam, and adjust its angle so that the reflected beam hits the movable mirror in its center. Now, with a screen in the position shown in the diagram, you should see two spots. Check that one comes from the movable mirror, and the other from the fixed mirror.

Question 3: How can you tell which beam comes from which mirror?

Now use the knobs on the fixed mirror to make the two spots overlap as well as you can. Finally, place a diverging lens (from your optics kit) on the front of your laser, and align it so that you get a big spot of light on your screen. You should see fringes in the spot. These fringes are part of a circular fringe pattern. Carefully adjust the knobs on the fixed mirror so that you get wider fringes (i.e., fewer fringes for a given angular extent θ , or smaller t). You can move the movable mirror by turning the micrometer dial on the side of the bench. Try it slowly, and make sure you can see the fringes shifting.

Measurement of wavelength Figure out a relationship between the change in mirror position, the number of fringe shifts in the interference pattern, and the wavelength of the light. Calculate the wavelength and your uncertainty, and compare it with the He-Ne laser wavelength of $\lambda = 632$ nm.

Optical path distortion An interferometer of this sort is very sensitive to vibration. Try tapping the bench and table, and see if you notice shifting of the fringes. Try stamping your feet on the floor. Try speaking near one of the mirrors. Can you detect these vibrations? Describe what happens to the fringe pattern, and explain why.

Index of refraction of glass Find the rotating table (a flat, circular piece of metal, with a pin in the center and a long arm), and mount it in between the beam splitter and the moving mirror. The pin fits in the hole in the bench, and the arm should lie on the angular scale at the edge of the bench. Mount the glass plate supplied with your optics kit on a holder, and mount both on the rotating table. As you rotate the table, you should see fringes shifting in the interference pattern. Explain why. When the fringe shift changes direction, the beam is perpendicular to the surface of the glass plate. Starting with the beam perpendicular to the plate, count the number of fringes that go by as you rotate the table a known angle. Knowing this, the wavelength that you measured above, and the thickness of the glass plate, derive a method to calculate the refractive index of the glass.

Index of refraction of air Place the gas cell between the beam-splitter and the movable mirror, so that the beam goes through the cell. You may have to make some re-adjustments to get your fringe pattern back. Slowly pump the air out of the cell, and count the number of fringes that go by. Record the pressure on the gauge and the number of fringes that have gone by as you do this. Assume that the refractive index of air is directly proportional to the pressure. Plot your data, and obtain a value for the refractive index of the air in the laboratory, assuming that in a vacuum (air pressure=0), n is 1. Compare this value with theory.

White light interferometer Complete this section if you have some time remaining after completing the other sections of the lab. For this part of the experiment you will need to find the position where $t = 0$. This is not easy when you consider that the movable mirror must be placed in the correct position to within a fraction of a wavelength. The point where $t = 0$ may be recognized as the point where the fringes will change their direction of motion as you move the mirror. Replace the laser with the light bulb. You should see fringes! (Tweak the movable mirror around a bit if you have to). Why? Think about monochromaticity $\lambda/\Delta\lambda$, and how many waves can interfere with white light and the eye as a detector.