MODERN INTERFEROMETRY LAB MANUAL

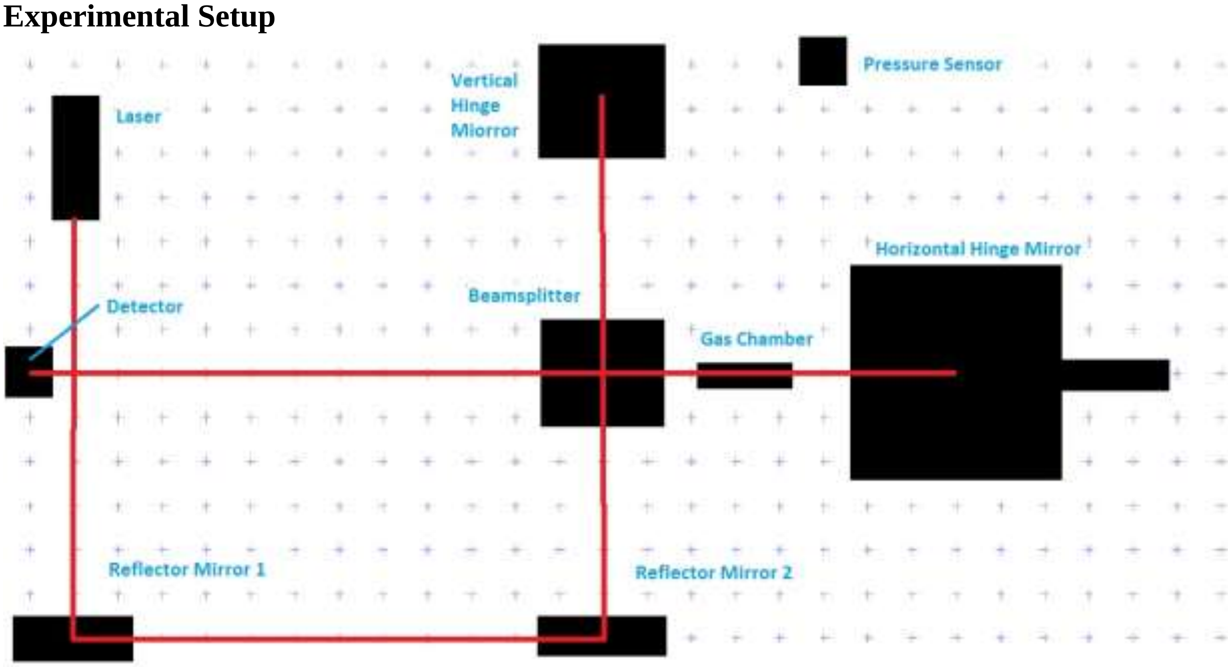
Introduction

The modern use of interferometry has its roots in the late 19th century when scientists first used light interference principles as a measurement tool. Today, we have more precise equipment and more accurate detectors but the same principles are used that scientists in the 1800s relied on. Today, interferometry is used in a variety of applications, including the measurement of small displacements, refractive index changes, surface irregularities, and vibration among others. We use interferometers that fit on laboratory table all the way to planned interferometers orbiting in space with distances between detectors of 5 million kilometers. One of the most well-known interferometer experiments was the famous “failed experiment” of Michelson and Morely which motivated the development of the theory of special relativity.

Materials

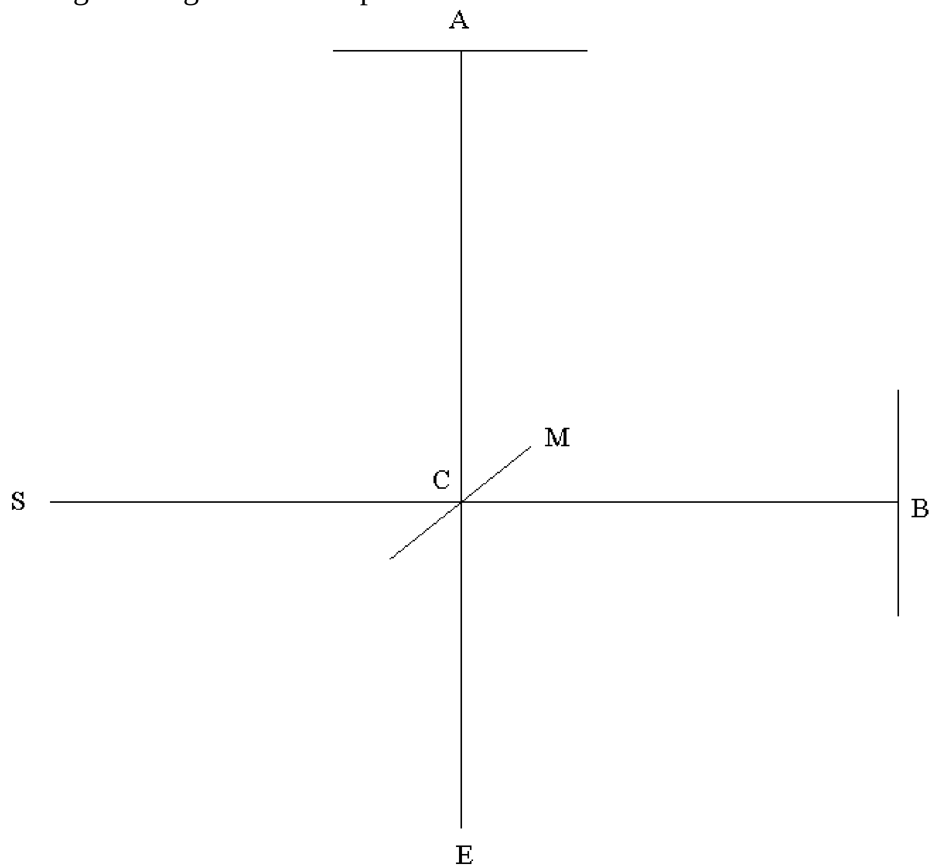
- HeNe Aligning Laser
- Diode Laser
- 2 Reflector Mirrors
- Beamsplitter
- Verticle Hinge Mirror
- Horizontal Hinge Mirror
- Gas Chamber
- Pressure Sensor
- Circumvolve Governor
- Pressure Pump
- Oscilloscope
- Power Supply

Experimental Setup



Theory and Apparatus

The basic idea of interferometry is the principle of superposition. When two waves of the same frequency combine, we can look at the new wave for information about phase differences of the original two waves. If the two original waves have no difference in phase, they interfere constructively and we see an increase in intensity of their light, if the two original waves have a phase difference of π, they perfectly cancel each other in destructive interference and we see nothing. A diagram of a simple interferometer is shown below.



A source laser at point S emits monochromatic light that then hits surface M at point C. Surface M is a beam splitter which splits the laser light into two beams, one in the direction of A and the other in the direction of B. At points A and B are mirrors which reflect the beam back to surface M, which recombines the two beams and then reflects the beam to point E, the observer. If the two beams are in phase, the observer will see an image no different than if he simply observed the laser without any reflectors or mirrors. However, if the two beams are out of phase the observers will see patterns of destructive interference.

A difference in phase can be induced by two methods. The first method is by slowing one of the waves down by forcing it to travel through a medium with a speed of light less than c, the second method is by forcing one of the waves to travel a longer distance than the other. This apparatus allows the experimenter to change both the medium the light travels through and the distance that the light travels. Included in this interferometer is a gas chamber for use in determining the index of refraction of different gases, and a linear displacement knob with a motor which moves one of the mirrors by very small amounts in order to determine the wavelength of light.

Procedure

Measuring Wavelength of Light

After turning on the laser, computer, and recording equipment, and aligning the board components so that the recombined wave is directed into the detector, ensure that the oscilloscope is receiving a signal, this will involve trial and error by adjusting the display range of the oscilloscope. In order to test that your oscilloscope is calibrated correctly, ensure that there is a signal visible on the oscilloscope when the laser is directed into the detector as well as a signal visible when the detector is covered with a piece of paper, blocking the laser from entering the detector. Blocking the laser approximates what happens when the laser beams combine destructively.

We will use the method of forcing one beam of light to travel a longer distance in order to determine the wavelength of light. This is done by introducing a small displacement to one of the mirrors, making one beam travel a longer distance than its counterpart. As the distance is changed you will see the voltage readout showing a change from constructive, to destructive, back to constructive. To illustrate, imagine that the distance the wave travels is increased by exactly one wavelength. This will not result in any change to the interference pattern, since the waves combine in the exact same manner that they did previously. However, if the displacement is equal to half of the wavelength, that beam is now out of phase with the other beam, and they combine destructively. By measuring the displacement needed to change the recombined waves from constructive to destructive, we can infer what the wavelength of the laser light is.

First, you must determine how quickly the motor turns the adjustment knob. This can be done by timing how much distance the motor changes per minute (this is done by looking at the tick marks on the adjustment knob). After you have established a relationship between time and distance for the motor, attach the motor to the adjustment knob using the groove carved in the knob. Ensure that the computer is on and open the labview program for this experiment. Press the run button on labview to ensure that the computer is recording the output from the detector. Now turn on the motor and watch the voltage oscillate between two values on the computer, the high voltage corresponds to constructive interference and the low value corresponds to destructive interference. The voltage will not drop to zero even when there is destructive interference because the laser light still has a width, and there are many waves overlapping at any given point in time. After running the experiment for 30 seconds, turn off the motor and stop the computer from recording. We are interested in the time between each cycle of the voltage readout on the computer. To get an accurate reading, average the times between cycles recorded to give a smoother value. From the relationship between time and displacement of the motor, you can determine how much displacement there is between cycles. Using this information, determine the wavelength of the laser. Make sure your calculations take into account the fact that the light travels the shorter distance twice, rather than traversing it just once. The value you come up with should match fairly closely with the experimental value for red light.

Measuring Index of Refraction of Gases

For light propagating through a material with index of refraction n, the wavelength λ varies according to:

$$\lambda = {}^{\lambda_0}/_{n}$$

where λ_0 is the wavelength of the light in vacuum. At relatively low pressures, the index of refraction is linearly proportional to the pressure. When the pressure is zero, in a vacuum, the index of refraction is exactly one. In this part of the experiment, you will use the apparatus to measure the index of refraction of air, make a graph of the correlation between pressure and index of refraction, and find the slope of this graph to determine the index of refraction at various pressures.

Procedure:

1) Align the apparatus as described earlier.
2) Make sure the gas chamber and vacuum pump are hooked up to the gas control station (with all of the knobs on it)
3) Remove the detector and ensure that the laser interference patter is clearly visible.
4) Be sure that the air in the gas chamber is at atmospheric pressure. This is done by sealing all of the knobs on the gas control station except for the one leading to the syringe. Then open up the syringe to allow air to flow into the gas chamber, then reassemble the syringe. This will ensure that the gas chamber's pressure is at atmospheric pressure. Mark this as your initial pressure, P_i, using the pressure detector for pressure readings. Make sure that these measurements are absolute pressure readings, not measurements with respect to atmospheric pressure.
5) Mark a reference point between a pair of fringes on your viewing screen. Slowly pump air into the gas chamber using the syringe to some convenient pressure level. As you do this, count the number of fringes that pass your reference point, Δm. Also record your final pressure, P_f, from the pressure detector.
6) As the laser passes back and forth between the beam splitter and the horizontal hinge mirror, it passes through the gas chamber twice. While in the chamber, the wavelength of the light gets shorter as the pressure is increased.

   Suppose that initially the chamber length, d, was ten wavelengths long (it's much longer in reality). As you pump gas into the chamber, the wavelength decreases until the chamber is 10.5 wavelengths long. Since the light travels through the chamber twice, it goes through one more oscillation as it passes through the chamber. This essentially is the same effect as part 1, where the adjustable hinge mirror is moved away from the beamsplitter by a ½ wavelength, and one fringe will have moved past the reference point in the interference pattern.

   At first, there are $m_i = 2d/\lambda_i$ wavelengths of light in the chamber, and at the final pressure there are $m_f = 2d/\lambda_f$ wavelengths in the chamber. The Δm you counted as you pumped air into the chamber is difference between these two values. Thus:

   $$\Delta m = \left|\frac{2d}{\lambda_i} - \frac{2d}{\lambda_f}\right|$$

   But also, $\lambda_i = \lambda_0/n_i$ and $\lambda_f = \lambda_0/n_f$ where n_i and n_f are the initial and final values for the refractive index of the air in the chamber. Thus

   $$\Delta m = \frac{2d(n_f - n_i)}{\lambda_0} \text{and} (n_f - n_i) = \frac{\Delta m \lambda_0}{2d}$$

   Therefore, the slope of the pressure graph is calculated by:

$$\frac{n_f - n_i}{P_f - P_i} = \frac{\Delta m \lambda_0 / 2d}{P_f - P_i}$$

Use the above equation to calculate the slope of the n vs. pressure graph.

7) Repeat this procedure at least 10 times, with different initial and final pressures to get an average value for the slope of the n vs. pressure graph.
   Some of these trial can be done starting at a vacuum. This can be done by closing the valve to the syringe and opening the valve to the vacuum pump, turning on the pump and pumping out all of the air, resealing the valve to the pump and reopening the valve to the syringe. This will cause the syringe to push all the way in. To take measurements, pull the syringe all the way out to its maximum volume for your initial pressure.
8) Using the average slope, plot n vs. P (you know that for P=0, n=1, so n= (slope)xP + 1).
9) Using n = (slope)xP + 1, what is n_{atm}, the index of refraction of air at atmospheric pressure? For the HeNe laser at room temperature, the accepted value for the index of refraction of air is 1.00028. Is your experimental value for n_{atm} within the estimated error of the accepted value?