

Observing Fringe Pattern with a Vertical Michelson Interferometer

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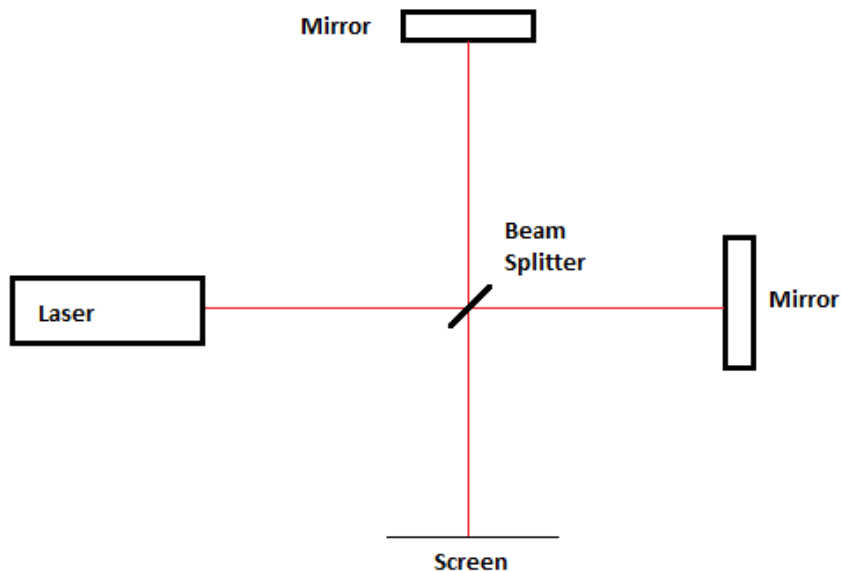
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Abstract

The objective of this project is to use a vertical Michelson Interferometer to examine the thermal expansion of a clear liquid. The shift in the fringe pattern produced by the interferometer will be used to explore the relationship between the index of refraction, the coefficient of thermal expansion, and the change in temperature. To learn about the techniques used in interferometry the Michelson-Morely experiment was examined. A Michelson interferometer was then constructed to apply these techniques to observe the thermal expansion. The interferometer has to be built in a vertical orientation in order for this expansion to be observed with interferometry.

Introduction

In 1887 Albert Michelson and Edward Morley preformed an experiment in order to detect the affects of the ether wind on the speed of light. The set up they used was a Michelson interferometer, the basic layout in figure 1.

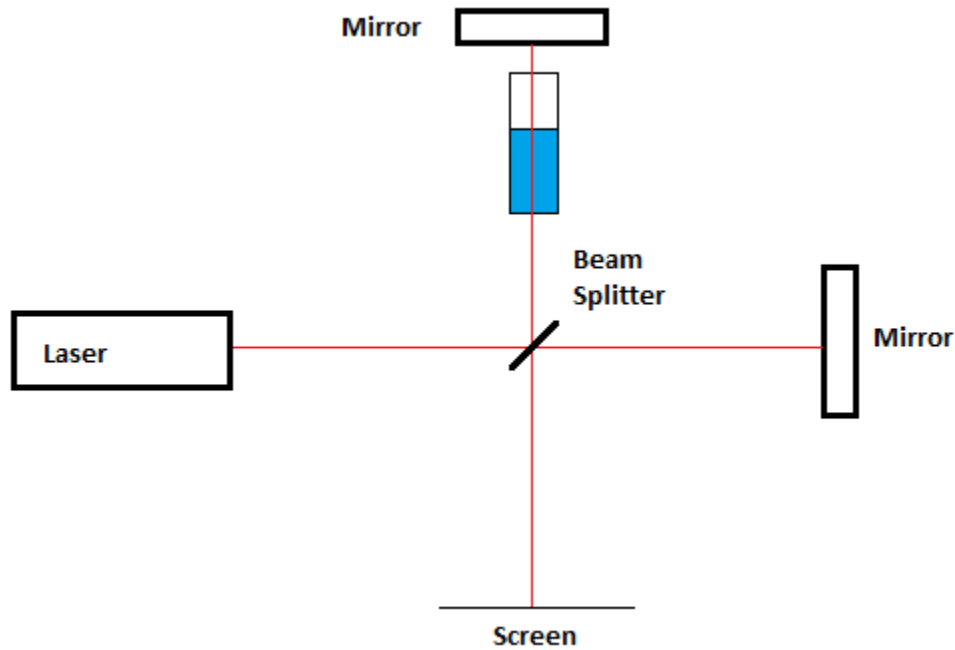


To dampen the effects of vibrations they set up their interferometer on a large sandstone block. The sandstone block was also placed upon a pool of mercury, which allowed the entire apparatus to spin. As the beam was split each resulting beam was reflected back and forth many times before being recombined. This was done in order to lengthen each path and would allow the hypothetical effects of the ether wind on the light to be larger and easier to be observed. The path lengths were extended to about eleven meters. Michelson and Morley hypothesized that since the Earth is theoretically moving through this ether the resulting relative “wind” would cause one beam in the interferometer to change speeds and form an interference pattern with the other unaffected beam. The apparatus needed to be able to turn to observe the interferometer at every possible angle in relation to the ether wind. This experiment was performed at many different times of year to account for the position of the earth. The results of this experiment were that there was practically no difference in the interference patterns. This went against their hypothesis and was a significant step in disproving the ether wind theory. After this experiment Michelson and Morley went onto establishing the wavelength of light as a standard of length. This technique involves moving a single mirror in the Michelson interferometer and observing the resulting fringe shift. The number of fringes (N) that shift is directly related to distance (d) the mirror is moved and the wavelength of the light (λ) as shown in the following equation.

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

This project involved using the techniques developed by Michelson and Morley and using them to observe the thermal expansion of a liquid. In order to do this I built a Michelson interferometer. Unlike normal interferometers that are horizontal that sit on a table top, my interferometer was constructed in a vertical orientation. To observe the thermal expansion of a

liquid, a container of the liquid would be inserted into the vertical beam path.



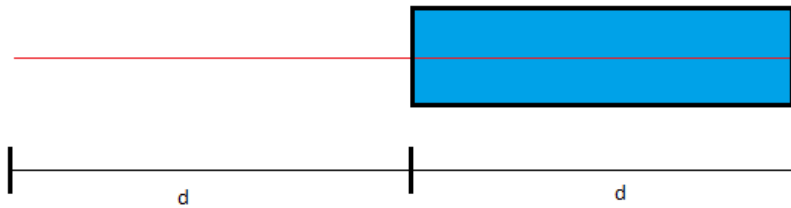
Heat would then be applied to the water causing a change of temperature to occur along with a thermal expansion. The vertical orientation of the interferometer is important so that the water is able to expand along the laser's path. The idea of this is to use the expansion of the water, instead of moving the mirror as Michelson and Morley did, to cause the change in the interference pattern. This means that observing the number of fringe shifts can be used to measure the amount the water has expanded. Taking it a little further the number of fringes can then be related to the coefficient of thermal expansion and the index of refraction of the liquid.

Theory

To explore the thermal expansion of the water in relation to the number of fringe shifts the equation previously stated is used.

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

But instead of using the distance the mirrored moved (d) the change in the height of the water is needed. To figure out the change in the laser's path length it's necessary to look at the path before and after the change in temperature. Before the heat is applied the path can be observed as:



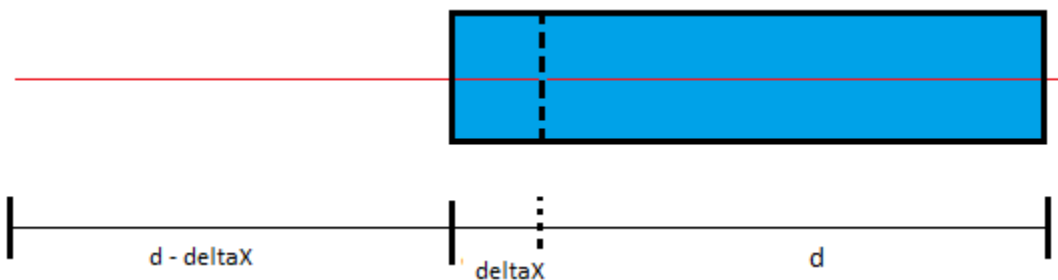
To simplify the equations assume the length the path runs through air is the same as the length through the water (x). With c being the speed of light through a vacuum and n being the index of refraction the time it takes the water pass through this leg is:

$$t_1 = \frac{d}{c} + \frac{d * n}{c}$$

And the effective length of this leg is found to be:

$$D'_1 = d(n + 1)$$

After the change of temperature this leg of the laser's path is:



The time it takes the light to pass through this leg is found to be:

$$t_2 = \frac{d - \Delta x}{c} + \frac{(d + \Delta x) * n}{c}$$

And the effective distance it travels is:

$$D'_2 = d - \Delta x + (d + \Delta x)(n)$$

To find the change in the laser's path length that will be observed in the fringe shift the difference between the effective distance should be found

$$\Delta D' = D'_2 - D'_1 = \Delta x(n - 1)$$

So finally the equation of the number of fringe shifts is found to be

$$N = \frac{2(\Delta x)(n - 1)}{\lambda}$$

But more interesting the expanded version of equation 7, gives a relation between the number of fringes, the thermal coefficient, and the index of refraction.

$$N = \frac{2(x_i)(\alpha)(n - 1)(\Delta T)}{\lambda}$$

With this equation observing the fringe shifts at different temperature changes will give interesting insight to the thermal expansion of water.

Method

I constructed my Michelson interferometer using an old wood kitchen countertop as my vertical base. I chose this as my material because it was decently heavy which would help with vibration dampening and it was very flat. A hollow box was built out the back of the countertop base, this was done to stabilize the base and allow weight to be added to the overall apparatus.



The added weight was used to further dampen vibrations. The vertical base measured 25' x 18'. Due to the size of the vertical base and the size of the laser to be used, a separate laser stand also had to be constructed. The laser stand can be seen on the left of the picture below. This wasn't the ideal set up with laser; I would have preferred it to be attached to the main apparatus. This set up was chosen because a smaller laser was being used in the early stages of construction.



The laser used was a He-Ne laser with a wavelength of 632.8 nm. In addition to the hollow back for weights, to dampen vibrations further the apparatus and laser stand were both mounted on large rubber pads. These pads are those that are usually used for washing machine and clothes dryers. The layout of the optical elements can be seen in the figure above. Two front surface mirrors were mounted at the ends of each optical path. Front surface mirrors were used as oppose to back surface mirrors to reduce the number of materials the laser had to go through. Back surfaces mirrors would diminish the focus of the reflected beam. They were both mounted on stationary brackets. At the center of the interferometer a 50/50 beam splitter was set in an eye hook to split and recombine the beam. This allowed it to be easy to rotate to align with the

mirrors.

To be able to observe the interference pattern a beam expander needed to be inserted into the interferometer. A close up of the configuration can be seen in below



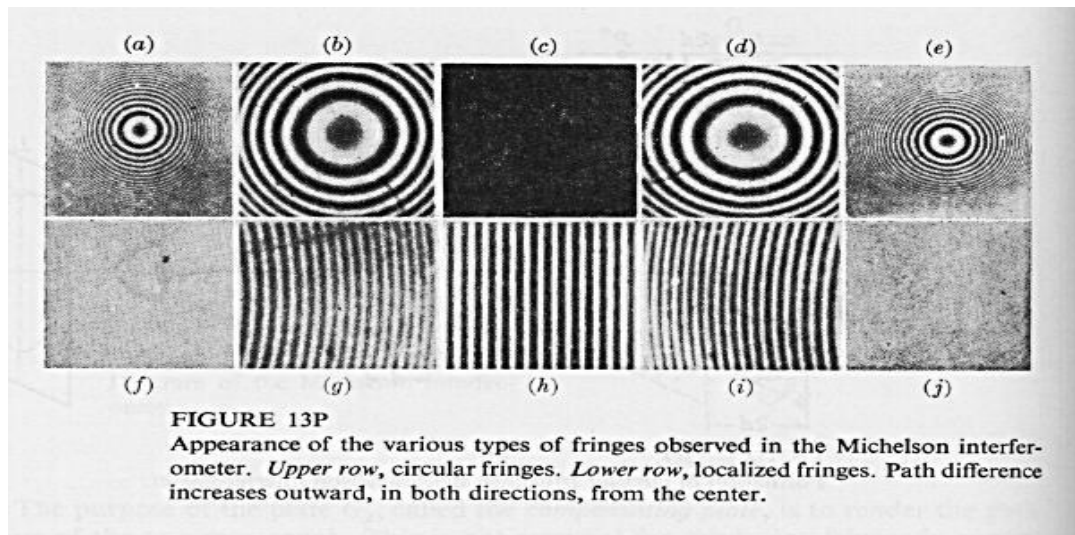
This set up is modeled after a Galilean telescope; it uses a diverging lens to expand the beam and a converging lens to refocus the beam. In my expander I used a 10 cm diverging lens with a 15 cm converging lens. This set up produces a magnification of 1.5. This was also a late addition so the space available was not significant enough to build a more powerful expander. The container for the water was constructed of clear glass. It was important the bottom of the container was flat and clear so that the laser would not be deflected passing through it. The sides of the container

were also constructed flat for a possible experiment. A simple self was attached to the vertical base of the interferometer for the container to sit on. There were also holes on the base so that the container could be strapped to the base.

Once the interferometer is constructed, alignment of the laser beams is needed to observe a visible fringe pattern. From a visible fringe pattern the water container is inserted into the apparatus. Using nichrome wire wrapped around the container heat is added to the water. This causes a change in temperature and a change in the height of water. For each change in temperature the number of fringe shifts is counted.

Results/Findings

Once the interferometer was constructed producing the fringe shift became the main goal of this project. After many tedious and fine adjustments a visible fringe shift was observed. The fringe pattern observed was a partial fringe pattern; it looked like a collection of fine vertical lines. In the picture below the resulting fringe pattern looked similar to (g) or (i).



The lines did appear to begin to curve near their ends, meaning that a complete fringe pattern was close. A complete fringe pattern consists of many concentric circles, like a bull's eye or (b) in the picture above. A complete fringe pattern was not produced because a perfect alignment was achieved. This fringe pattern was too unstable to continue with the water portion of the project. Once the container of water was inserted into the interferometer the fringe pattern became too unfocused to be observed. The surface of the water proved to be too reflective to have the laser pass through without altering its path. If the water surface was able to be set up perfectly horizontal allowing the laser to pass straight through it would be too hard to keep that balance. Any small vibration altered the water's surface and sent the laser in different directions.

Conclusion

As this project progressed the scope of it narrowed. As I started I aimed to perform the entire experiment to explore the thermal expansion of water. But as I worked through the design and construction of the interferometer producing a visible fringe shift became difficult enough. If I was to go forward with project I would need to address some problems that I have found over the course of this project. I would like to build the interferometer bigger. A bigger set up would allow more space for a bigger beam expander, this would be essential if I wanted to actually count the fringe shifts. It would also allow the laser to be mounted to the same structure as the rest of the interferometer which I think would help with alignment. A negative aspect of a bigger set up would be the increase in vibrations throughout the apparatus. To further help with dampening the vibrations I would need to secure individual elements, such as the mirrors, more soundly. A possible way of doing this is mounting the elements in a clay-like substance. Another change would be with the beam splitter I used, with the given budget the one I was able

to get was very small, about 1.5 inches. The size of the beam splitter made alignment difficult and I think a larger one would help.

This project taught me a lot. I got to explore the broader subject of optics which I don't have large background in. And more specifically I got to look into the field of interferometry. I now find the field extremely interesting. I would have liked to take this project further but given the circumstances I was satisfied being able to produce a visible fringe pattern. I feel I have set a good foundation for future experiments and I hope someone is able to continue this project. During research on interferometry another possible experiment was found dealing with the index of refraction of a gas. The set up of the experiment is similar to the one proposed earlier but instead of a column of water a sealed container of a gas is used. In this experiment the interferometer can be in its original horizontal orientation. The idea for this experiment is to observe the change in the fringe pattern as a gas is removed from the sealed container. The change in the index of refraction would be the change from the gas to a vacuum. This experiment is actually a simpler and more practical experiment. In theory the results would be much simpler and show the relationship of the index of refraction and the number of fringe shifts.

Sources

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