**Experiment 7: Michelson Interferometer**

D. Crisp, Ariel

**Abstract**

The Michelson Interferometer is a very handy tool for determining the wavelength of light, and would be handy for light of several wavelengths due to how it allows for investigation of beat frequencies.

**Introduction**

Light is described as a traveling and oscillatory electromagnetic field whose field vectors at any given point are always perpendicular to its direction of motion. The oscillating amplitude of a field component will reach some maximum, decrease through zero as it reaches a maximum in the opposite direction, and then return through zero once more before reaching its initial orientation and amplitude. The distance light travels in the time required to perform one full oscillation as described is its wavelength, and the time it takes is its period. When two rays of light cross paths, the amplitude and direction of field components at that point of crossing is simply the addition of their respective field vectors. If you take two waves of equal wavelength—the same color—and send them along the same optical path, the addition of their fields will cancel each other out completely (destructively) if the maximum of one is seen at the same time and location as when the other is exactly opposite: when the relative phase of each wave is off by half an oscillation or 180 degrees in phase. Conversely, constructive interference is seen when the maximum field amplitude of one is seen at the same time and location as the others maximum: in other words when the phase difference between them is 0.

A Michaelson Interferometer is an optical set up that allows for the measurement of a light’s wavelength. It does this by splitting a beam of light from a single source in two, and directing each along separate optical arms of adjustable length before re-aligning them and sending them together to some diagnostic—where the wavelength is calculated based on characteristics of the observed interference pattern. Once split, the waves must continue to oscillate in the same way as they were when together, they continue to perform full oscillations at the same wavelength. But by adjusting the length of one arm and not the other, one can force one beamlet to traverse an extra distance before being re-aligned with the other. This optical path difference creates a relative phase difference between the two such that an interference between the two can be observed. In this lab, we simply used our eyes as a diagnostic to identify and measure the resulting interference pattern and its characteristics. A micrometer was used to make measurable adjustments in the movement of a rod that then moved a lever which in turn shortened or lengthened one arm of the interferometer. Note that due to the lever, movement measured on the micrometer needs to be divided by a factor of 5 to define the effective change in distance for the arm. The other arm had adjustments for ensuring proper re-alignment of the two beams.

Once re-aligned, the two beams will radiate with their relative phase shift and create circular fringes. At the position of perception, bright circles of constructive interference will be separated by dark circles of destructive interference. However, if the path of the two beams is not well enough aligned, these circles are effectively centered far out of view and appear instead as lines.

A Mercury [Hg] lamp was used as a light source with a known wavelength of 5461 Angstroms or .

**Analysis & Discussion**

With the Mercury lamp as a source supplying light at 546.1 nm wavelength at the entrance of the Michelson Interferometer, we attempted to view the expected interference pattern with the naked eye. This proved difficult at first due to the fine spacing of the interference fringes, and the length of an arm had to be adjusted to first recognize the lines through their movement across the plane. This effect is due to poor re-alignment of the split beams, so adjustment of the pitch and yaw of one arm’s mirror was done to center the interference pattern within view—effectively improve the re-alignment of beam paths. There was some trial and error involved as it was impossible to first determine in what direction the center was. Though the center of the pattern could be expected to be either top right or bottom left, say, it was not possible to determine whether the fringe lines were moving towards the top right or away from the bottom left so there was some trial and error. What helped the most was realizing that the fringe lines grew thicker and more widely spaced when making correct adjustments.

Once the interference pattern was centered, an effort was made to get the optical path difference as close to zero as possible. It was observed that as the mirror was moved in, shortening the optical length of that arm, the fringes moved toward the center: the opposite is true for moving the mirror in the other direction. At the value where the fringes appeared to neither move outward or inward is where we took the optical path length to be as close to zero as possible. Another observation is that the center fringe was larger than it was in other positions. This length was read out from the micrometer: which equates to after considering the lever efficiency. This extra factor applied due to the lever improves the resolution of our measured adjustments to the arm’s length. There was an assumption that this micrometer had been calibrated and the lever efficiency verified.

An effort was again made to find the distance where the optical path length is zero, except now having replaced the Hg light source with one producing what could be described as white light. I use the phrase ‘described as’ because white light is somewhat of a misnomer, the light appears white but is really a composite of at least three varieties of light each with their own characteristic wavelength. Here the difficulty was not with aligning the light beams, as that had already been done, but with finding the where the optical path difference was zero, the point where the central fringe is a result of each light beam being in phase with each other. Since white light is a composite of at least several colors of light, the resulting interference pattern—whose properties is dependent on the wavelength—is also a composite of at least several independent interference patterns. As these patterns do not lie nicely on top of each other as light of the same wavelength does, the destructive fringes everywhere get washed out by the consistent presence of one or several constructive fringes from any pattern of the white pattern composite, and no fringe bright or dark will be observable at all. With great attention, the path length was changed with the micrometer until an interference could be observed. While changing one arm’s length, our view went from blanket white to a bright rainbow of concentric circles, though the range of positions where this was visible was very small. **Q1**At the position of zero path difference, the fringe spacing for each composite colored light was largest and least likely to overlap, so the constructive fringe of one color could be seen unadulterated as it lay comfortably within the destructive dark fringes of the other color’s patterns. The center fringe appeared bright as expected because each light component contributes constructively with a zero-path length. **Q2** I will note that I seemed to see the very center somewhat greyed out relative to the rest of this zeroth order constructive fringe, yet am unsure whether to attribute this effect to my eye being poorly adept at perceiving color and brightness of a bright white light for long enough periods of time, or because the location for where the optical path difference is zero is really an average of each light components position. This position of the micrometer was read as translating to .

The white light source was removed and one more we used the Hg source. This time, our goal is to identify how much interference fringes moved with a change of path distance made with the micrometer. One mirror had its yaw and pitch adjusted to purposefully place the patterns center off screen to observe more evenly spaced diagonal lines which would be easier to count as we changed one arm’s length. Starting at the micrometer’s zero path difference position for the Hg source of , 52 fringes were counted while moving the micrometer to . After taking the difference between these two values to be and dividing by five to account for the efficiency of the lever, we calculated that a change in path distance of translates to a visual, successive, passing of 52 interference fringes. More simply put, a change in position of per translation of one fringe. This measurement was found to agree exactly when repeating the measurement from the same starting point but moving in the opposite direction. It should be noted that it is very likely we may have been off by one or two fringe counts, where being off by two fringes translates to a relative error of . Remembering that a change in an arm’s length effects the path twice over since light traverses it in both directions before re-alignment, the wavelength can be calculated using with an error of . The error would have been increased by a factor of +/- 1.04 if we had been off by two fringes. Although this error is very significantly large, the value we reached is only 1.4% off from the expected 546.1nm.

Sodium, represented by the symbol Na, was also used as a light source. It appears as yellow light and has two dominant emissions in its spectra: 589nm and 589.6nm. At the zero difference in optical path, the fringe contrast was highest, just as it was with previous sources. But instead of a single component like Hg, Na has two and the fringe contrast decreases away from the zero OPD much like what was observed with white light. What is different with Na compared to white light is that if you go farther still from the zero OPD position, the fringe contrast returns. This is the effect of a beat frequency that occurs when two waves of different wavelengths are superimposed on one another. Recall that is the equation for finding ‘Small-d’, the distance from fringe to fringe. The error calculation is then .

|  |  |  |
| --- | --- | --- |
| Locations of beat maxima | Distance between beat maxima ‘Big-D’ | ‘Big-D’ With lever efficiency applied |
| 18.05 |  |  |
| 19.5 | 1.45 | 0.29 |
| 21.98 | 1.48 | 0.296 |

This table represents data taken in calculating ‘Big-D’: half the optical path difference needed to shift from one beat maxima (macro amplitude) to the next. The average difference is (without lever efficiency), but (with lever efficiency).

Multiplying ‘Big-D’ by 2 and dividing by 1 (since each were only one order apart from each other), one gets a lambda of 586um.

|  |  |  |
| --- | --- | --- |
| Positions before and after translating 50 fringes | Distance moved in counting 50 fringes | ‘Little-d’ Distance moved in counting 50 fringes with lever efficiency applied |
| 18.82 |  |  |
| 18.9 | 0.08 | 0.016 |

This table represents data taken and calculated for ‘Little-d’, half the optical path difference which causes 50 fringes to pass a single point as seen from our eye. ‘Little-d’ is after having applied the 1/5 lever efficiency.

Multiplying by 2 and dividing by 50 (dividing by 25), gets us a lambda of 640nm.

**Conclusion**

It is clear that a Michelson Interferometer is a very useful tool for investigating properties of interference patterns. Though it seems to be somewhat difficult to determine the zero path difference.

A sizeable improvement to this lab would be to include a more sensitive diagnostic instead of the naked eye. That being said, a value for the wavelength of Hg light was found that matches quite well.

Measuring the wavelength of Hg light returned a number for wavelength of which agrees quite nicely with the expected 546.1 nm.

White light is very difficult to measure due to the variety of colored light comprising it. The range where any contrast can be seen is severely limited about the zero path length.