The Michelson Interferometer

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Abstract: We report spectral properties of two different light sources—a red diode laser and a sodium lamp—measured using the Michelson interferometer. We measure the wavelength of the laser to be $\lambda = 664 \pm 4$ nm, and the sodium source to be $\lambda = 629 \pm 2.5$ nm. We also perform an experiment to calculate the distance between constituent wavelengths of the sodium source, known as the sodium D lines or Fraunhofer lines. This experiment involves measuring visibility maxima in a similar fashion to fringes, and we report a wavelength difference of 70 nm.

I. Introduction

In this lab, we aim to use a Michelson interferometer set-up to measure wavelength properties of light. A Michelson interferometer is an apparatus that splits light into two separate components, which then travel varying path lengths before recombining (Figure 1). Depending on relative phase, the light interferes with itself and produces a pattern we can measure. This technique is a clever way to introduce different phase relationships between beams of light, and provides a means for measuring its wavelength by measuring how changes in path length affect the interference pattern produced. In this experiment, we aim to make three measurements on two different light sources—a red diode laser and a sodium lamp. We will measure the wavelength of light produced by both sources, and perform a third experiment to measure the difference between the two closely spaced sodium D lines. In measuring the wavelength of the sodium source, we really determine an average of these two closely spaced spectral lines.

II. Experimental Setup

Light of interest is first sent to a beam-splitter, which reflects $\sim 50\%$ of the light and transmits the rest. Both portions of the beam are reflected back to the beam splitter by mirrors after traveling down their respective arms. When light arrives back at the beam-splitter, half of the total light goes back toward the source, and the remaining half is the recombination of the two arms (Figure 1). Any difference in path length between the two arms is a difference in phase between the two light waves. Phase changes of $\lambda$ cause the interference pattern to repeat itself. By measuring the path length change between a pattern we observe and its repeat, we can determine values for $\lambda$. 
Figure 1: The Michelson interferometer. The adjustable mirror is mounted on a micrometer, allowing us to finely measure the distance, $d$, changed in that arm. For an added distance of $d$, path length changes by $2d$. Therefore, the interference pattern repeats when $2d = \lambda$.

For part 1, the wavelength measurement of a red diode laser, we mount and align the laser to the interferometer. By projecting the interference pattern on a viewing screen, we can adjust the micrometer and count how many “repeats” occur in the pattern. Since the change in phase, $\lambda$, equals the change in path length, $2d$, we equate the two and solve for $\lambda$.

A similar method is implemented to measure the wavelength of the sodium lamp source. We align the source with the interferometer, and look into it to measure the interference pattern rather than projecting it onto a screen. The sodium lamp is much less coherent than the laser, so the fringes produced are much less defined. By projecting the pattern directly onto the retina of an observer, we can discern fringes and once again count the number of repeats in the pattern for a certain path length change to find the wavelength.

The wavelength measurement of the sodium source was actually a measurement of two closely spaced spectral lines produced by the source. The obtained value for $\lambda$ corresponds to the average value of these two lines. The difference between them is calculated by measuring repeats in visibility of the fringes. When the fringes appear maximally visible, the two wavelengths of the source are both in phase. When one wavelength is in phase with itself but the other is not, the fringes appear blurred. Therefore, repeats in visibility correspond to an integer number of $\lambda$ phase changes for both wavelengths. This is given by eqn 1:

$$D = m_1 \lambda_1 = m_2 \lambda_2$$

Using the path length-wavelength relationship, we derive an expression for the difference in the wavelengths:

$$\lambda_1 - \lambda_2 = \frac{\lambda_1 \lambda_2}{2d}$$
III. Results

For the laser diode wavelength measurement, we performed 5 trials. In each trial, we measured the change in mirror distance corresponding to 50 repeats in the interference pattern projected on the screen. This allowed us to obtain a much more accurate value for the distance per repeat, by simply dividing the measured distance by 50. We measured $\lambda = 664.4 \pm 4$ nm.

For the wavelength measurement of the sodium D lines, 6 trials were performed in which we counted either 20 or 50 repeats in the pattern, depending on visibility conditions in the region. These distance measurements gave an average $\lambda = 629 \pm 2.5$ nm.

In determining the two component wavelengths of the sodium light source, we used equation 2 along with the equation obtained from the result of the last experiment:

$$\frac{\lambda_1 + \lambda_2}{2} = 629 \text{ nm} \tag{3}$$

These two equations provide ample information to solve for the two unknowns $\lambda_1$ and $\lambda_2$. We determined that $\lambda_1 = 594$ nm and $\lambda_2 = 664$ nm. This corresponds to a difference in wavelength $\lambda_1 - \lambda_2 = 70$ nm. The known values for these two spectral lines, known as Fraunhofer lines, are 589.59 nm and 588.995 nm, giving a difference of .597 nm. The average is $\lambda = 589.29$ nm. Our value of 629 nm gives an error of 6.7%.

IV. Discussion

Although the precise value of the laser diode is not exactly known, it is roughly calibrated to be near 650 nm. Pasco does not make it clear how close to this approximate value the wavelength is, but our determined value of 664 ± 4 nm gives a small error of 2.2%. This suggests the experiment was successful, and given a more accurate known value from a spectrometer, the actual wavelength could reasonably be within our calculated error of 4 nm.

The determined average wavelength of the sodium D lines was longer than the well known value of 589.25 nm [1]. Although this measurement only gives 6.7% difference, the known value is well outside the estimated error of 2.5 nm. I believe this discrepancy can be explained by a systematic error in our procedure that caused us to measure longer distances per fringe—the unnoticed tendency to skip fringes. Since the interference pattern was measured directly with our eye, and due to the incoherence of the sodium source, it was difficult to count fringes perfectly. Often times, it seemed fringes could have been scanned by unnoticed, causing us to divide the total distance by a smaller number of fringes than actually occurred. This type of error would explain our obtained larger value for wavelength.

The only way to explain the huge error in our measured values for the two constituent wavelengths is a misunderstanding of the notion of “visibility.” Although we noticed very distinct repeats in the clarity of the pattern, they were extremely far apart, and can probably be explained by other means. Apparently, the visibility maxima and minima we should have been noticing were more subtle and closely spaced. This would not reduce the error in the calculation of our center wavelength, but it would correct the huge separation we found between the constituent wavelengths, which should have been less than a nanometer.

References