LABORATORY WRITE-UP
MICHELSON INTERFEROMETER LAB

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MICHelson interferometer

1. PURPOSE

The purpose of this experiment is to give some practice in using a Michelson Interferometer to measure the index of refraction.

This instrument is probably best known in connection with the Michelson-Morley experiment, in which an unsuccessful attempt was made to demonstrate the existence of an "ether", a hypothetical medium supposed to be necessary for the propagation of electromagnetic waves. The versatility of the interferometer will become apparent in the following experiment in which you will measure the mean of the two dominant wavelengths emitted by a sodium lamp as well as their difference, the refractive index of mica, and the refractive index of air.

The interferometer is shown in Fig. 1 of your lab manual. DO NOT ALLOW YOUR FINGERS TO TOUCH ANY OF THE OPTICAL SURFACES. An extended light source is provided by a lamp, L, often monochromatic, and a ground glass diffusing screen, S. The instrument itself consists of two parallel-sided glass plates, G1 and G2, and two front-surfaced plane mirrors, M1 and M2. The distance from G1 to M1 is defined as d1 and similarly the distance from G1 to M2 is defined as d2. The rear surface of G1 is partially silvered so that light from the source is partially transmitted towards M2 and partially reflected towards M1. The light reflected back by M1 is partially transmitted through G1 to the observer’s eye while that from M2 is partially reflected to the observer’s eye. The purpose of the "compensator", G2, is to make the paths in glass the same for the two rays. (Essential when using white light.) M1 is mounted on a carriage, which can be moved perpendicularly to itself by a micrometer screw. A lever system provides a 5:1 reduction between the movement of the micrometer and mirror.

To obtain circular interference fringes, M2 is made exactly perpendicular to M1 by means of adjusting screws on M2. Rays parallel to the central ray shown in Fig. 1 of your lab manual will interfere constructively at the eye if the path difference, \( 2d = m\lambda \), where \( d = |d_2 - d_1| \). [“m” is the order of the fringe here.] Thereafter, successive movements of distance \( \lambda/2 \) by M1 will also fulfill this condition. Parallel rays making an angle \( \theta \) with the axis interfere constructively if \( 2d \sin \theta = m\lambda \). The net result is concentric circular fringes corresponding to appropriate values of \( \theta \). "Localized fringes" which are virtually parallel can also be produced by making M1 and M2 not quite perpendicular to each other. Both types will be used in this experiment.
2. **PROCEDURE**

**Preliminary adjustments:** Switch on the power supply for the sodium lamp with the current control in position 3. Adjust the current to approximately 0.9 A, but not exceeding this value. Place a small loop of wire to the right of the diffusing screen. Four images should be visible, two of which are more intense from back reflection from \( G1 \) and two weaker ones from front reflection. Adjust the screws on \( M2 \) until corresponding pairs coincide. Localized fringes will probably be visible at this point. Continue adjusting the screws, making the fringe spacing larger, until circular fringes are seen centered in the field of view.

**Mean wavelength of the sodium D lines:** These spectral lines are due to atomic transitions from the \( ^2P_{1/2} \) and \( ^2P_{3/2} \) states to the ground state. Their wavelengths differ by approximately 0.5 nm.

Move the mirror \( M1 \) over relatively large distances and note how the visibility of the fringes varies periodically. Lowest visibility occurs when one wavelength is producing constructive interference for a given \( \theta \) and the other is producing destructive interference. Adjust \( M1 \) for maximum visibility of the fringes with a dark fringe at the center. Note the micrometer reading to the nearest tenth of the smallest division, i.e. to the nearest 0.001 mm. Turn the micrometer very carefully counting the number of fringes which disappear at the center of the pattern. When 100 have disappeared, record the new micrometer reading and calculate the mean wavelength. Repeat the procedure a few times and calculate an average. (You will probably need some practice for this. It is very easy to miss a fringe.)

[Hint: To find the average distance, be sure to remember the “divide by 5” mentioned above. Then write down algebraically the equation for a fringe at order \( m \) and at order \((m+100)\). Subtract the two equations.]

**Difference between the wavelengths of the sodium D lines:** Adjust \( M1 \) to a position of minimum fringe visibility and note the micrometer reading. Move \( M1 \) until you have passed through several minima and hence calculate the average distance, \( x \), that \( M1 \) has to be moved between successive minima. Calculate the difference, \( \delta \lambda \), between the wavelengths from the formula

\[
\delta \lambda = \frac{\lambda^2}{2x}
\]

Where \( \lambda \) is the mean wavelength obtained above.

**Refractive index of mica:** For this you will use white light fringes which are only visible if \( d1 \) and \( d2 \) are very nearly equal. They may be found as follows: Using the sodium lamp, obtain vertical localized fringes by slight adjustment of the screws on the back of \( M2 \). If \( d1 < d2 \), the fringes will be slightly curved concave as shown in Fig. 2a of your lab manual. If \( d1 > d2 \), they will be convex as in Fig. 2b of your lab manual. When \( d1 = d2 \), they will be straight, as in Fig. 2c of your lab manual. Adjust the micrometer until you obtain straight fringes, and then replace the sodium lamp with the white light source. Make minor adjustments to the micrometer until the white light fringes become visible.

\[ d1 < d2 \quad d1 > d2 \quad d1 = d2 \]
Center the fringes in the field of view and read the micrometer. Insert the sheet of mica into one of the light paths and find out how far \( M_1 \) has to be moved to re-obtain the white light fringes. Measure the thickness of the mica with a micrometer screw gauge and hence determine the refractive index of mica.

**Refractive index of air**: The refractive index, \( n \), of a gas is very nearly equal to the value of unity for a vacuum. If temperature, \( T \), remains constant, \( n \) varies linearly with pressure, \( p \):

\[
    n = 1 + \left( \frac{\partial n}{\partial p} \right)_T \cdot p
\]

For discrete changes in \( p \), we may write

\[
    n = 1 + \left( \frac{\Delta n}{\Delta p} \right)_T \cdot p
\]

\( \Delta n / \Delta p \) is measured for air contained in a sealed cylinder with glass end windows, which is placed in one arm of the interferometer. The distance, \( l \), between the windows is 5 cm and will contain a number of waves, \( N \), given by

\[
    N = \frac{n}{\lambda}
\]

where \( \lambda \) is the wavelength in a vacuum. If the pressure is now changed by \( \Delta p \), the refractive index of the air changes by \( \Delta n \), and the number of waves in the tube changes by \( \Delta N \), where

\[
    \Delta N = \frac{\Delta n}{\lambda} \cdot l
\]

As a result, \( 2\Delta N \) fringe shifts in the field of view will be counted.

Attach the cylinder to the interferometer in the arm containing \( M_1 \). BE VERY CAREFUL NOT TO TOUCH ANY OPTICAL SURFACE. Connect the cylinder with flexible tubing to the hand-operated vacuum pump as shown in Fig. 3 of your lab manual. The additional flask allows the pressure in the cylinder to be controlled more finely.

![Fig. 3 System for measuring refractive index of air](image)

Using the sodium lamp, obtain a good set of circular fringes. Operate the pump until the pressure in the system has been reduced by 60 cm of Hg. You may need to wait until the temperature, and therefore the pressure, has stabilized. Adjust the position of \( M_1 \) to obtain a bright fringe at the center of the pattern. Very carefully squeeze the vacuum release trigger on the pump and count the number of fringes, \( 2\Delta N \), which disappear at the center of the pattern as the cylinder pressure returns to atmospheric. You should be able to count to the nearest half fringe. Measure atmospheric pressure and, using equations 1 and 2, determine the refractive index of air for the mean sodium wavelength.
Obtain the refractive index $n_0$ at normal temperature and pressure (273 K and 76 cm of mercury) using the relation

$$(n - 1)T/p_a = (n_0 - 1)273/76$$

where $T$ is room temperature and $p_a$ is atmospheric pressure.

3. GRAPHS AND CALCULATIONS

4. CONCLUSIONS

State the conclusions you reached from this lab.