Physics Lab Report

Experiment Title： Measuring Laser wavelength and Index of Refraction of Air by Michelson Interferometer

Student Number： 2016200302027

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Instructor： Jing Wu

Date Performed： 12th October

Score

Abstract (About 100 words, 3 points)

The aim of this experiment is to measure the wavelength of the laser and measure the index of refraction of air. This experiment uses the method of split amplitude to generate two beams which could help them to realize the interference.

After this experiment I understand how I could operate the Michelson interferometer. And by using these instrument, I could calculate and measure the wavelength of the laser and the index of refraction of air.

After performing this experiment and analyzing the data:

- I should able to understand the production of interference pattern in the Michelson interferometer.
- I should understand how the Michelson interferometer is used to measure a small displacement.
- Understand the principles it used in the Michelson interferometer.

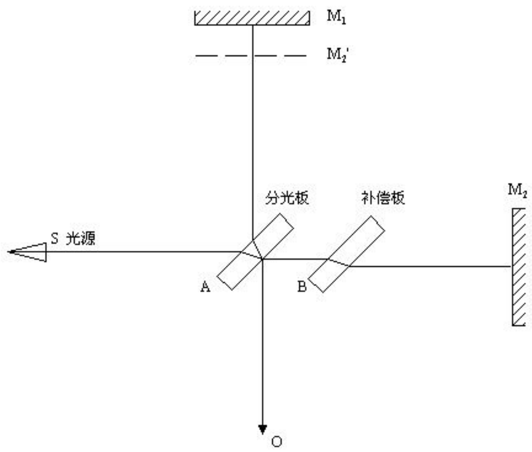
I also know that light would have interference phenomena and we can use Michelson interferometer to calculate its wavelength and the index of air.

Score

Introduction (3 points)

Michelson interferometer is a precision optical instrument which was designed and manufactured by American physicist Michelson and Morey in 1887 in order to study the drift of the ether.

It uses the method of split amplitude to generate two beams which could help them to realize the interference. By adjusting the interferometer, it can generate the interferogram of equal-angle and equal-length. These apparatus are mainly used for measuring the wave length and wave's refractive index. If one of the interference fringes is observed and moved, the distance of the arm is moved in the distance of $\frac{\lambda}{2}$, which is equivalent to the thickness change of the air film between M1 and M2.



Such apparatus has important applications in the modern physics and modern measurement techniques, such as the fine structure of spectral lines and the standard meter rule with light wave calibration. Based on his instrument and principle, a variety of special interferometers are developed nowadays.

He also received a Nobel prize in physics in 1970 because of this experiment and the measurement of the speed of the light. He is also the first American to win this award.

The interferometry refers to measurements that relay on the interference of two (or more) light beams. Interferometers are widely used in science and industry for the measurement of small displacements, refractive index changes and surface irregularities.

Score

Experimental Procedure (State main steps in order of performance, 3 points)

The experiment can help us to measure the wavelength of the laser and measure the index of refraction of air.

Measuring the Wavelength of Laser.

1. Turn on the power of each component in this experiment.
2. Adjust the equipment and make sure that we can see two(lightest) laser spots in the center of beam splitter.
3. Adjust the apparatus and make the two lightest laser spots to coincide into a spot.
4. Put the beam expander between the laser and the beam splitter and adjust its height to illuminate the beam splitter.
5. Now, we can see the interference pattern on the beam splitter and adjust the apparatus to let the pattern to be at the center of the screen.
6. Rotate the big wheel of interferometer and don't stop until you see the motion of the interference fringes. And rotate the small wheel in the same way until you can see the new pattern generated.
7. Then, read the scale interferometer and record it. Rotate the small wheel and count the number of the new pattern that

generated. When it has 50 new patterns, record the scale.

8. Repeat the last step for 5 times. Record the necessary data.
9. Put every equipment back to the right place and process the data and write the report.

Measuring the Index of the Refraction of Air.

1. Turn on the power of each component in this experiment.
2. Adjust the equipment and make sure that we can see two(lightest) laser spots in the center of beam splitter.
3. Adjust the apparatus and make the two lightest laser spots to coincide in to a spot.
4. Put the beam expander between the laser and the beam splitter and adjust its height to illuminate the beam splitter.
5. Now, we can see the interference pattern on the beam splitter and adjust the apparatus to let the pattern to be at the center of the screen.
6. Open the air valve(counter-clockwise) by a couple of turns.
7. Squeeze the handle of the vacuum pump several times to evacuate the cell.
8. Then, read the pressure on the apparatus and record it.
9. After that, let the air flow out of the apparatus smoothly and count the number of the new pattern that generated. When it

has 60 new patterns, record the end pressure.

10. Repeat the last two steps for 3 times. Record the necessary data.
11. Put every equipment back to the right place and processing the data and write the report.

Score

Results (Data tables and figures, 2 points)

3.8.5 Experimental Data

Data Table 3.8-1 ***Purpose*****: To measure the wavelength of He-Ne laser**

N	0	50	100	150	200	250
d/mm	48.47343	48.48910	48.50304	48.51050	48.5364	48.5400
Δd_i/ mm	$\Delta d_1=\lvert d_{150}-d_0\rvert=$ 0.06261		$\Delta d_2=\lvert d_{200}-d_{50}\rvert=$ 0.04634		$\Delta d_3=\lvert d_{250}-d_{100}\rvert=$ 0.3486	
$\Delta\bar{d}=\frac{\Delta d_1+\Delta d_2+\Delta d_3}{3}$ / mm	0.04794					
$\bar{\lambda}=\frac{2\Delta\bar{d}}{\Delta m}=\frac{2\Delta\bar{d}}{3\times50}$ / nm	640					

Data Table 3.8-2 ***Purpose*****: To measure the index of refraction of air**

Room temperature $T=$ 24.0 ℃; Atmospheric pressure $p = 1.013\ 25\times10^5$ Pa;
$L = 95.0$ mm; $\lambda_0 = 633.0$ nm; $m = 60$

Trial	1	2	3
p_1 /MPa	0.094	0.087	0.104
p_2 /MPa	0.019	0.018	0.036
$\Delta p_i=\lvert p_2-p_1\rvert$ /MPa	0.075	0.069	0.068
$\Delta\bar{p}=\frac{\Delta p_1+\Delta p_2+\Delta p_3}{3}$ /MPa	0.071		
$n=1+\frac{\lambda_0}{2L}\frac{60}{\Delta\bar{p}}p$	1.00031		

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Score

Discussion (More than 150 words, 5 points)

Through the two experiments above, we can get the laser wavelength and the refractive index of air, although this is only a small part use of the Michelson interference instrument. This is also the initiate use of this set of apparatus.

In the experiments, we record the data every 50 or 60 times change of the interference fringe, which is a kind of method to minimize the measuring error or some man make mistake. Also, we repeat every experiment for tree times and get the results, which can reduce the man make error and increase the accuracy.

In this experiment, it uses two mirrors to reflect the light and form the path distance of the light. The distance can generate the interference which could help us to see the image on the splitter. So the interference and the generating of the path difference is the main theorem of this experiment.

We repeated this experiment for many times, so we can use the mean value theorem to minimize the error and make the result of this experiment more accurate.

Score

Conclusions (About 50 words, 2 points)

The calculation steps are in the appendix.

6.1 Compute the wavelength of He-Ne laser and its uncertainty

(1) Compute the mirror displacements.

$\Delta d_1 = d_{150} - d_0 = 0.06261mm$ $\Delta d_2 = d_{200} - d_{50} = 0.04634mm$
$\Delta d_3 = d_{250} - d_{100} = 0.03486mm$

(2) Compute the averaged mirror displacement.

$$\Delta\bar{d} = \frac{\Delta d_1 + \Delta d_2 + \Delta d_3}{3} = 0.04794mm$$

(3) Compute the wavelength of He-Ne laser.

$$\bar{\lambda} = \frac{2\Delta\bar{d}}{\Delta m} = \frac{2\Delta\bar{d}}{3\times 50} = 0.00064m = 640nm$$

(4) Compute relative error of the wavelength of He-Ne laser.

$$E_{\bar{\lambda}} = \frac{\bar{\lambda}-\lambda_0}{\lambda_0}\times 100\% \approx 1.11\% \quad (\lambda_0=633.0 \text{ nm})$$

(5) Compute the type A evaluation of uncertainty in $\Delta\bar{d}$.

$$\mu_{A_{\Delta\bar{d}}} = \sqrt{\frac{(\Delta d_1-\Delta\bar{d})^2+(\Delta d_2-\Delta\bar{d})^2+(\Delta d_3-\Delta\bar{d})^2}{n(n-1)}} = 0.00007mm = 70nm$$

(6) Compute the type B evaluation of uncertainty in $\Delta\bar{d}$.

$$\mu_{B_{\Delta\bar{d}}} = \frac{\Delta_{Instr.}}{\sqrt{3}} = 0.00003mm = 30nm \quad (\Delta_{Instr.} = 0.00005 \text{ mm})$$

(7) Compute the combined uncertainty in $\Delta\bar{d}$.

$$\sigma_{\Delta\bar{d}} = \sqrt{{\mu_{A_{\Delta\bar{d}}}}^2 + {\mu_{B_{\Delta\bar{d}}}}^2} = 0.00007$$

(8) Compute the uncertainty in $\bar{\lambda}$.

$$\sigma_{\bar{\lambda}} = \frac{2\sigma_{\Delta\bar{d}}}{\Delta m} = 1\times 10^{-6}m = 1nm \quad (\Delta m=3\times 50)$$

(9) The final result of the laser wavelength.

$$\lambda = \bar{\lambda} \pm \sigma_{\bar{\lambda}} = 640nm \pm 1nm$$

The calculation steps are in the appendix.

6.2 Compute the wavelength of He-Ne laser and its uncertainty

(1) Compute changes in pressure.

$\Delta p_1 = p_{12} - p_{11} = 0.075Mpa$ $\Delta p_2 = p_{22} - p_{21} = 0.069Mp$

$\Delta p_3 = p_{32} - p_{31} = 0.068Mpa$

(2) Compute the mean value of the changes in pressure.

$$\Delta\overline{p} = \frac{\Delta p_{1+}\Delta p_{2+}\Delta p_3}{3} = 0.071Mpa$$

(3) Compute the index of refraction of air at atmospheric pressure.

$$n = 1 + \frac{\lambda_0}{2L}\frac{60}{\Delta\overline{p}}p = 1.00031 \quad (p=1.01325\times10^5\text{Pa})$$

(4) Theoretically, the index of refraction of air at atmospheric pressure can be calculated by the following equation

$$n_0 = 1 + \frac{1.00031p}{1 + 0.003671\times T}\times10^{-9} \approx 1.00038$$

where *p* is atmospheric pressure in Pa, T is the room temperature in Kelvin. Compute the theoretical value of the index of refraction of air

(5) Compute the relative error of *n*.

$$E_n = \frac{n-n_0}{n_0}\times100\% \approx -0.069\%$$

The calculation steps are in the appendix.

Score

References (1 points)

Some parts I write on this prelab which is references from Wikipedia and Baidu.

Some parts of my report was got from the book (Introductory physics experiments for undergraduates, Haofu)

Some of the words and formulas are from materials on BB9. Calculations were down by my partner Yue and me Musk.

Score

Answers to Questions (6 points)

(1) Why are several light spots on the screen before the beam expander in placed in the light path?

Apparatus in this experiment includes four glasses, two reflecting plates, fixed mirror and moveable mirror in these apparatus. The laser would pass through the middle of the glass and are divided into two coherent laser beams. These two beams pass through the mirror finally displayed on the beam splitter. Because there are four surfaces of the two glasses, it has reflections which is more than two times. So, there are more than one spot on the screen.

(2) You are required to rotate the wheel in one direction when you count the passing fringes, Why?

Although the apparatus is precise, it is not seamless especially it has distance between gears. In order to get one precise scale, we need to minimize the distance between the gears and do not let the small wheel to run in blank. So, we need to let it rotate in a direction to eliminate the error.

(3) In the experiment of measuring the laser wavelength, we see that the interference pattern. Interpret it in terms of the changing of optical path difference?

The result is formed because of the optical path difference, when we use the wheel, the path difference changed, the interference condition also changed. So, the dark fringes become bright, and the bright fringes become dark, so we can see that the interference fringes of light are moving.

Appendix

Score

(Calculations, 15 points)

Calculated by me and my partner.

3.8.6.

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University of Electronic Science and Technology of China

(1) $\Delta d_1 = |d_{150} - d_0| = |48.50524 - 48.47343| = 0.06261\,mm$

$\Delta d_2 = |d_{200} - d_{50}| = |48.53604 - 48.48970| = 0.04634\,mm$

$\Delta d_3 = |d_{250} - d_{100}| = |48.54010 - 48.50524| = \cancel{0.03486}\ 0.03486\,mm$

(2) $\Delta \bar{d} = \frac{\Delta d_1 + \Delta d_2 + \Delta d_3}{3} = \frac{(0.06261+0.04624+0.03486)mm}{3} = 0.04784\,mm$

(3) $\bar{\lambda} = \frac{2\Delta \bar{d}}{\Delta m} = \frac{2 \times 0.04784mm}{3 \times 50} = 0.00064m = 640\,nm$

(4) $E_{\bar{\lambda}} = \frac{\bar{\lambda} - \lambda_0}{\lambda_0} \times 100\% = \frac{640.0 - 633.0}{633.0} \times 100\% \approx 1.11\%$

(5) $\mu_{A\Delta\bar{d}} = \sqrt{\frac{(\Delta d_1 - \Delta\bar{d})^2 + (\Delta d_2 - \Delta\bar{d})^2 + (\Delta d_3 - \Delta\bar{d})^2}{n(n-1)}}$

$= \sqrt{\frac{(0.06261 - 0.04784)^2 + (0.04634 - 0.04784)^2 + (0.03486 - 0.04784)^2}{285 \times 284}}$

$= \sqrt{\frac{0.00022 + 0.00000 + 0.00017}{285 \times 284}}$

$= 0.00007$

(6) $\mu_{B\Delta\bar{d}} = \frac{\Delta_{instr}}{\sqrt{3}} = \frac{0.00005\,mm}{\sqrt{3}} = 0.00003\,mm$

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(7) $\sigma_{\Delta\bar{d}} = \sqrt{\mu_{A\Delta\bar{d}}^2 + \mu_{B\Delta\bar{d}}^2} = 0.00007$

(8) $\delta_{\bar{\lambda}} = \frac{2\delta_{\bar{d}}}{\Delta m} = \frac{2\times 0.00007}{3\times 50} = 1\times 10^{-6} = 1\,nm$

(9) $\lambda = \bar{\lambda} \pm \delta_{\bar{\lambda}} = 640\,nm \pm 1\,nm$

3.8.6.2

(1) $\Delta p_1 = |p_{12} - p_{11}| = |0.019 - 0.094| = 0.075\ MPa$

$\Delta p_2 = |p_{22} - p_{21}| = |0.018 - 0.087| = 0.069\ MPa$

$\Delta p_3 = |p_{32} - p_{31}| = |0.036 - 0.104| = 0.068\ MPa$

(2) $\Delta\bar{p} = \frac{\Delta p_1 + \Delta p_2 + \Delta p_3}{3} = \frac{(0.075 + 0.069 + 0.068)MPa}{3} = 0.071\,MPa$

(3) $n = 1 + \frac{\lambda_0}{2L} \cdot \frac{60}{\Delta\bar{p}} p = 1.00031$

(4) $n_0 = 1 + \frac{1.00031\,p}{1 + 0.003671\times T} \times 10^{-9} \approx 1.00038$

(5) $E_n = \frac{n - n_0}{n_0} \times 100\% \approx -0.069\,\%$

Appendix

(Scanned data sheets)

3.8.5 Experimental Data

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$\Delta\bar{d} = \frac{\Delta d_1 + \Delta d_2 + \Delta d_3}{3}$ / mm	0.04794					
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$\Delta\bar{p} = \frac{\Delta p_1 + \Delta p_2 + \Delta p_3}{3}$ /MPa	0.071		
$n = 1 + \frac{\lambda_0}{2L}\frac{60}{\Delta p}p$	1.00031		

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