Michelson's Interferometer

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Objective

To study the working of the Michelson Interferometer, using it to calculate the wavelength of light from the interference fringe patterns produced and calculating the index of refraction of air with respect to vacuum.

Setup and Procedure

The initial setup of the interferometer requires that the beam splitter is placed so that the incident beam reaches it at an angle of 45°. At this angle, the beam is split into two components: one of these is reflected from the beam splitter at an angle of 90° from the initial beam and hits mirror 1 while the other passes through the beam splitter in the same direction as the initial beam and hits mirror 2. Since the interference pattern depends on the difference in path length, such that for constructive interference $D = N\lambda$ and for destructive interference, $D = \left(N + \frac{1}{2}\right)\lambda$ where D is the difference in path length and λ the wavelength of the incident light.

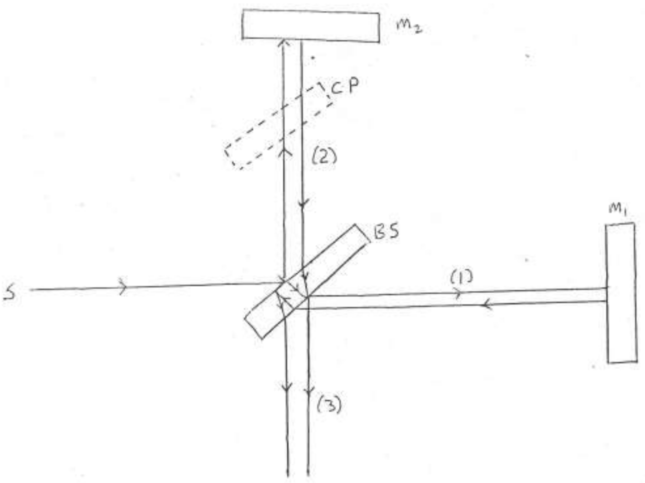

Figure 1

The mirrors were initially setup so that the distance of each mirror from the beam splitter was the same (20.0±0.1 cm) so that the difference in path length was entirely due to the total internal reflection on one side of the beam splitter and the uncertainty in measurements.

The path length can be further varied by changing the angle at which the beams hit the mirrors, which is visible in the interference pattern on the screen. Since the nature of the interference depends on the phase difference, if the path lengths are equal and the beams reach normal to the surface, the interference pattern should be concentric circles. The radii of concentric circles would then depend on the difference in path length. Patterns other than circles would mean that the mirrors are not exactly perpendicular to each other.

Once the mirrors were properly aligned, the micrometer screw was used to move one of the mirrors until a specific number of fringes passed a mark on the screen. The wavelength of the light beam was calculated using the distance moved by the micrometer screw (*D*) and the number of fringes (*N*) where:

$$\lambda = \frac{2D}{N}$$

In the second part of the experiment a vacuum chamber was added to the path of one of the beams and the same approach was used to calculate an experimental values for the index of refraction of air with respect to vacuum using the relation above, where the difference in phase is created only by the effective difference in path length ie.

$$D = nL - L = L(n-1)$$

Where *L* is the length of the vacuum chamber. This gives us:

$$\lambda = \frac{2L(n-1)}{N} \rightarrow \; n = \frac{N\lambda}{2L} + 1$$

Data and Analysis

Calculations of uncertainty which propagates through according to:

$$\delta y = \sqrt{\left(\frac{\partial y}{\partial x_1}\right)^2 (\delta x_1)^2 + \left(\frac{\partial y}{\partial x_2}\right)^2 (\delta x_2)^2 + \cdots + \left(\frac{\partial y}{\partial x_n}\right)^2 (\delta x_n)^2} \quad where\ y = y(x_1, x_2, \dots x_n)$$

Assuming an uncertainty of 2 μm in the micrometer measurements and an uncertainty of 1 in the counting of fringes, the uncertainty in the counting is almost negligible in comparison

Using the above relations and a beam of Red light, we found:

	Number of fringes ($\pm$1)	**Distance (in $\mu m \pm 2\ \mu m$)**	**Experimental wavelength (in nm)**
1	50	16	640$\pm$80
2	75	22	586$\pm$60
3	100	32	640$\pm$40

$$\lambda_{red} \cong\ 622 \pm 62 \text{ nm}$$

With the same method using green light, we found:

	Number of fringes (± 1)	Distance (in $\mu m \pm 2\ \mu m$)	Experimental wavelength (in nm)
1	50	12	480$\pm$80
2	75	20	533$\pm$50
3	100	28	560$\pm$40

$$\lambda_{green} \cong 524 \pm 57 \text{ nm}$$

With the vacuum chamber (L = 8.1$\pm$0.5cm) in the path of one of the beams, we measured the number of fringes to pass the mark on the screen for the two wavelengths (colors) of light used above. We used the experimentally calculated values of wavelength in these calculations to give us:

Color of light	Number of fringes (± 1)	Experimental wavelength (in nm)	Value of index of refraction
Green	53	524$\pm$57	1.00017$\pm 2\times 10^{-5}$
Red	43	622$\pm$62	1.00017$\pm 3\times 10^{-5}$

$$n_{avg} = 1.00017 \pm 3 \times 10^{-5}$$

Questions

Were you able to discern any dispersion for air?

Yes, dispersion due to air was found in the form of the index of refraction for air which was found to be $1.00017 \pm 3 \times 10^{-5}$

To observe white light fringes, you must use a compensating plate. Why?

To observe white fringes you need a compensating plate because lights of different wavelength are refracted to different extents and therefore focus at different points. A compensating plate works by focusing the different wavelengths at the same point.

Could you devise a way to measure the index of refraction of a transparent solid?

The index of refraction of a transparent solid could be measured by placing the solid so that the light beam is incident at the critical angle. Then, we can use Snell's law for total internal reflection to find the index of refraction:

$$n_{material} = \frac{n_{air}}{\sin\theta_{critical}}$$

Conclusions

Our experiment had three bright spots instead of the two that were expected which suggests that there was some reflection taking place at the point of refraction that we did not account for.

For the first part of our experiment, we were not given the actual values of the wavelengths of the laser beams and we did not have values to verify the results of the experiment but the values were well within the expected range of wavelengths for each color.

For the second part of this experiment, our experimental value for the index of refraction of air was 1.00017 with a range of uncertainty of 2×10^{-5}while the expected value for the index of refraction was 1.00029. This discrepancy can be attributed to the limitations of the accuracy of the apparatus which suggests that we underestimated the uncertainties used in our analysis.