

Experiment 8

Michelson Interferometer

1 Introduction

The Michelson interferometer uses light interference to measure distances in units of the wavelength of light from a particular source. It was developed by Albert Michelson and used, in 1893, to measure the standard meter in units of the wavelength of the red line in the cadmium spectrum. It is also known for its use in demonstrating the non-existence of an electromagnetic wave-carrying “aether”. Contemporary uses include precision mechanical measurements and fourier transform spectroscopy.

In this laboratory, we will use a Michelson interferometer to (a) measure the wavelength of light from a Ne-He laser, (b) measure the index of refraction of air, and (c) study the interference of linearly polarized light beams.

1.1 How the Interferometer Works

A simplified version of the Michelson interferometer is shown in Figure 1. The basic idea is to split a beam of light into two beams; delay one with respect to the other, and then recombine them to observe their interference.

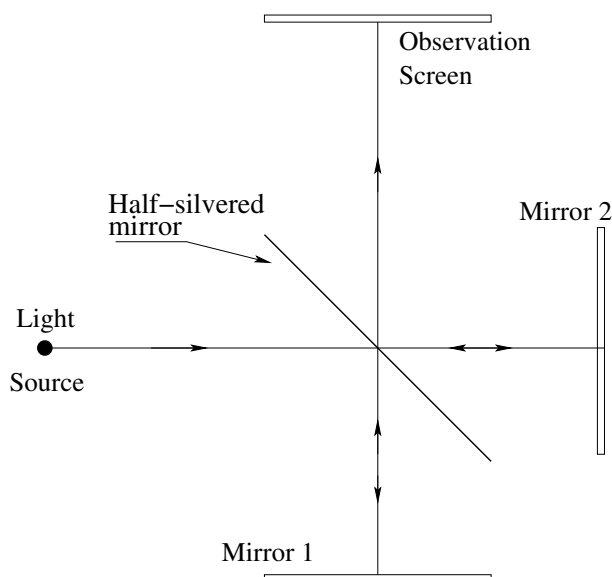
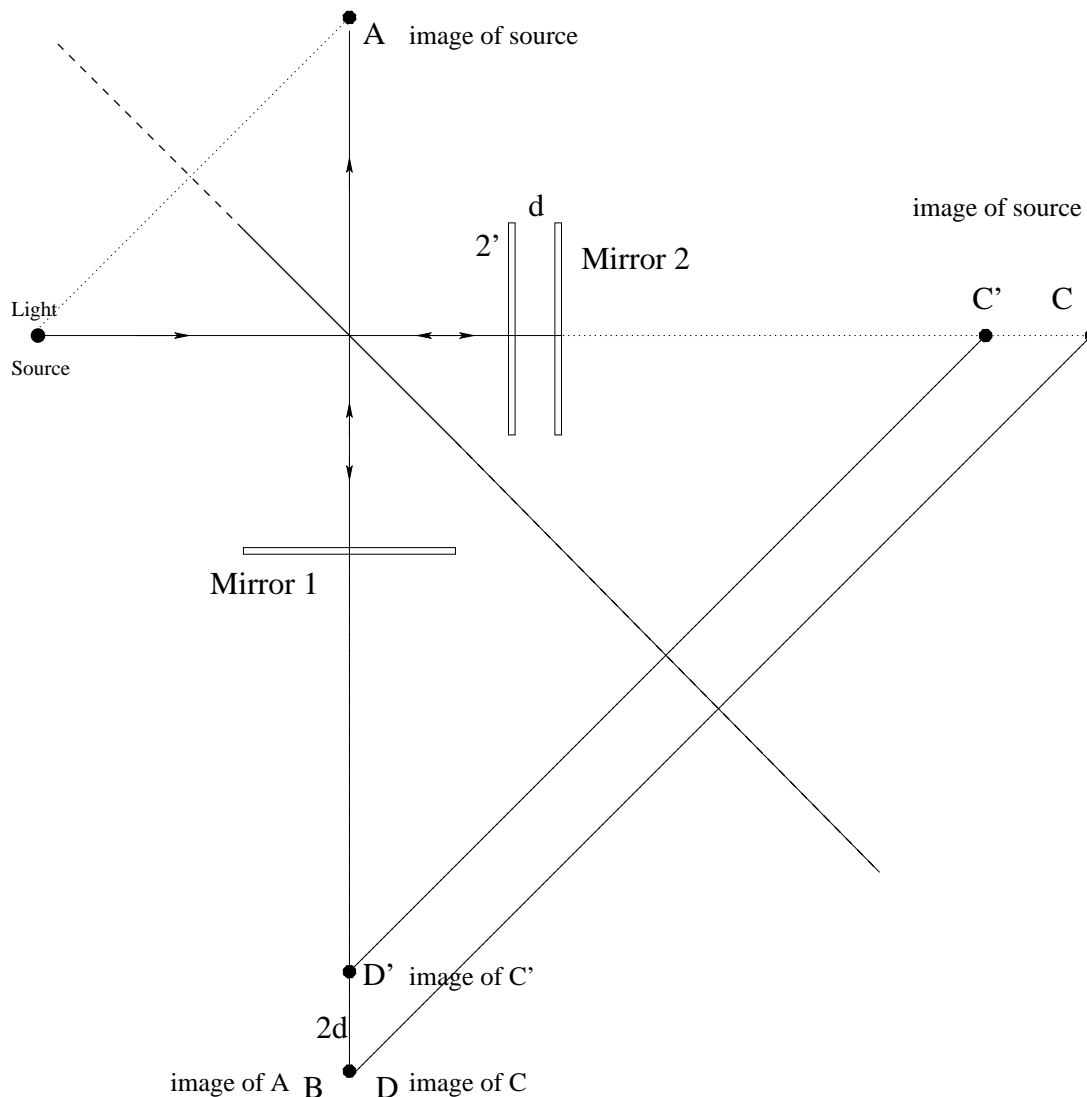


Figure 1:

Light from a monochromatic source is directed at a “half-silvered” mirror i.e. a mirror with a very thin metallic coating. Approximately half the light intensity is reflected down

If the light source is a point source, we can easily find its images made by the combination of mirrors. This is shown in Figure 2. The image of a point source is located “behind” the mirror, at the same perpendicular distance as the object.



In this case, A is the image of the source made by the half-silvered mirror. B is the image of A made by Mirror 1. C is the image of the source, for rays transmitted by the half-silvered mirror, made by Mirror 2, and D is the image of C made by the half-silvered mirror.

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But now suppose the Mirror 2 is closer, by a distance d , to the half-silvered mirror than Mirror 1, then C becomes C' and D becomes D' , which is a distance $2d$ closer.

The observer then sees two point sources of light, separated by a distance $2d$. There will be interference of these sources; it will be constructive interference if

$$m\lambda = 2d \quad (1)$$

where m is 0 or a positive integer, and λ is the wavelength of the light.

The two light sources emit light over an angular range. (In this experiment a lens is used to make the laser beam diverge.) A point on the observation screen, at an angle θ with respect to the sources, will be at constructive interference if

$$m\lambda = 2d \cos \theta$$

The geometry of this is illustrated in Figure 3 The resulting image on the observation

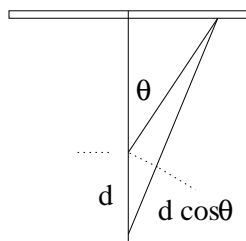


Figure 3:

screen will be a series of concentric, circular bright and dark rings. As Mirror 2 is moved, the fringes will change from bright to dark etc.

2 Apparatus

In this experiment we use the Pasco interferometer shown in Figure 4.

In our apparatus, the “compensator” is not installed. Mirror 2 is labelled the “movable” mirror in the Figure. It is moved toward or away from the beam-splitter mirror by turning the micrometer.

3 Procedures

3.1 Alignment Procedures

1. Turn on the laser, and look at the observation screen. If you see the ring pattern, and it can be changed by turning the micrometer screw, then the apparatus is aligned, and you may skip the remaining steps.
2. Take out the lens from the component holder next to the laser.

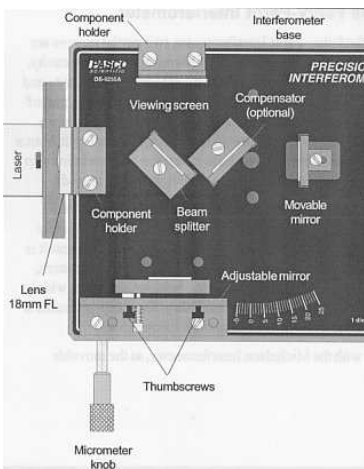


Figure 4:

3. Next, remove the beam-splitter mirror with a screwdriver. Turn on the laser beam, and adjust its position to direct the beam straight into the center of the the “movable” mirror (Mirror 2). The beam should be reflected right back into the laser.
A good way to find the beam is with a small piece of paper, or an index card.
4. Then restore the beam-splitter mirror and look at the observation screen. You may see two sets of small spots, one from each of the mirrors. In each set there is a bright spot, and several less-bright ones, which are produced by multiple reflections.
5. Use the adjusting screws on the “fixed” mirror (Mirror 1) to make the bright spots overlap each other. As you are doing that, the overlapping spots will twinkle, due to the interference of the beams.
6. Finally, restore the lens. Slide it around until you can see the ring pattern on the observation screen. It is OK to fiddle a bit the the laser orientation, if necessary.

3.2 Measuring Light Wavelength

1. Turn the microcrometer either clockwise or anti-clockwise for about 1 rotation. Then turn it, in the same direction, enough to see N fringes pass some point on the screen. N should be at least 20. Measure the number of ticks on the micrometer which correspond to the N fringes. Each tick is 1 micron ($10^{-6} m$). This corresponds to d in Equation 1. The wavelength is then

$$\lambda = 2d/N$$

2. Compare this with the known wavelength of 633 nm.

3.3 Measuring the Index of Refraction of Air

The index of refraction of a medium is

$$n = c/v$$

For a vacuum, $v = c$, so n is exactly 1. For gases, the index of refraction increases linearly with pressure, as shown in Figure 5.

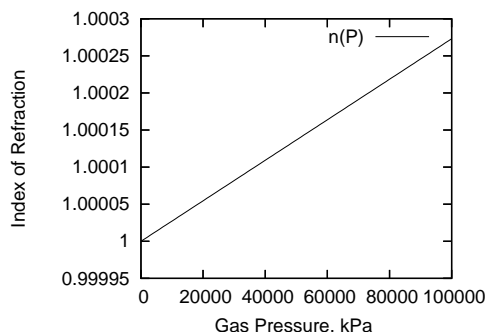


Figure 5:

We can express this as

$$n - 1 = P \frac{dn}{dP}$$

We then simply have to find the rate of change of the n with respect to pressure, P .

To do this, mount the air cell in front of Mirror 2, as shown in Figure 6, and connect it to the hand vacuum pump with the tubing.

Then slowly pump the air out of the cell, counting the number of fringe transitions as this is done. It is sufficient to reduce the pressure down to about $50kPa$. Record the file pressure, and find ΔP , using $101kPa$ as the starting pressure.

Now the light wavelength in a medium of index of refraction n is

$$\lambda = \frac{\lambda_0}{n}$$

where λ_0 is the wavelength in vacuum. Recall that when a wave traverses a distance x , its phase changes by

$$\Delta\phi = \frac{2\pi x}{\lambda}$$

In this case, if the thickness of the cell is t , since the light travels through it twice, the phase shift for constant n would be

$$\Delta\phi = \frac{2\pi 2t}{\lambda_0/n} = \frac{4\pi nt}{\lambda_0}$$

So, with the cell in place, with atmospheric pressure, we have a certain fringe pattern. When the air is pumped out, there are N fringe transitions, one for each phase shift of

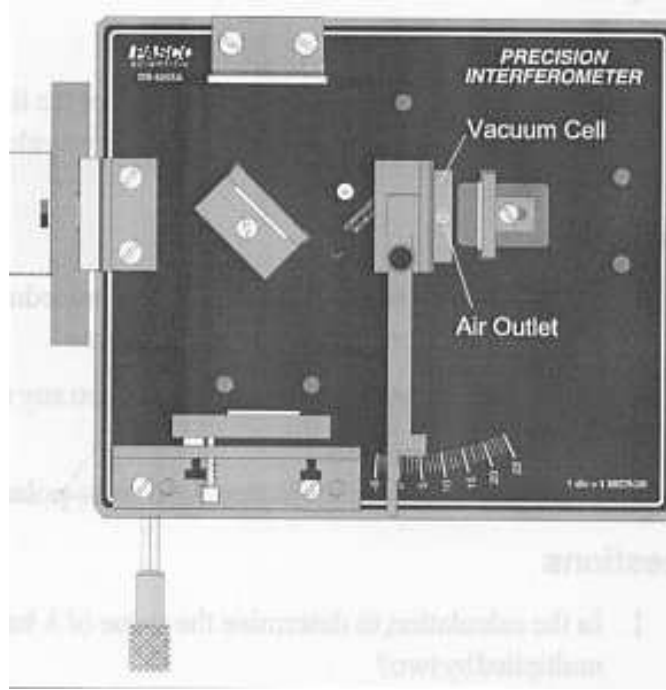


Figure 6:

2π . For a net change, Δn , in the index of refraction, the above equation gives

$$\frac{2\pi 2t \Delta n}{\lambda_0} = 2\pi N$$

so

$$\Delta n = \frac{N \lambda_0}{2t}$$

and

$$\frac{dn}{dP} \approx \frac{\Delta n}{\Delta P} = \frac{N \lambda_0}{2t \Delta P}$$

And so, finally,

$$n - 1 = \frac{P_A N \lambda_0}{2t \Delta P} \quad (2)$$

where P_A is atmospheric pressure, λ_0 is the light wavelength, and t , the thickness of the cell = 3.0 cm .

Compute $n - 1$ from the above equation, using the measured N , ΔP , and using $\lambda_0 = 633 \text{ nm}$. Compare this with the accepted value 2.73×10^{-4} for 1 atmosphere at 20°C .

3.4 Polarization Studies

Place one polaroid filter in front of the movable mirror, and one in front of the stationary mirror. Rotate one of the filters and observe what happens to the interference pattern. What can be concluded about the interference of two beams which are polarized at 90° with respect to each other?