F7. Interferometry

I. INTRODUCTION

Interferometry is the study and use of the interference phenomenon due to the wavelike properties of light. The phenomenon of interference occurs when two or more coherent oscillations (the same frequency and fixed relative phase) coexist in space and time, and overlap. In general, two methods of achieving interference fringes exist: by dividing the wavefront (Young slits, Fresnel mirrors, Fresnel biprism, etc.) and amplitude division (Michelson interferometers, Mach-Zehnder, Jamin, etc.). The latter is of great interest since we can separate a ray, manipulate each one individually before recombining them

Michelson interferometry

The basic working principle of this interferometer is indicated schematically in figure 1. The incident wave I_i, of wavelength λ_0, is divided into two beams using a semi-transparent material (called beam splitter, or BS). Part of it is transmitted (I_t) and the other part reflected (I_r). Each part being of lesser amplitude than the initial beam, they follow individual optical paths 1 and 2. I_t and I_r are then reflected by two mirrors M_1 and M_2 in order to recombine onto BS.

If the interference conditions are satisfied, the recombination of these waves produces their interference whose image can then be detected on a screen E, as long as the difference between the optical paths of I_r and I_t is less than the coherence length (see the more detailed documentation, found on location). This path difference is determined by the transparent medium 1 and 2 that I_r and I_t cross, as well as by the distances $BS-M_1$ and $BS-M_2$. We can show analytically and experimentally that:

For an appropriate adjustment of M_1 and M_2, the fringes obtained on E are rectilinear, circular, elliptic, parabolic or hyperbolic.

For any given interference pattern, a mirror displacement of $\lambda_0/2$ moves each fringe onto its neighboring fringe.

Therefore, in order to measure a difference in optical length, one must set the interferometer to get more or less parallel fringes, set one of the fringes as a starting point, and count the number N of fringes that pass by when moving a mirror by ΔL. One of the optical paths of $\mathrm{I_r}$ or $\mathrm{I_t}$ is lengthened, and we have:

$$\Delta L = N\lambda_0 / 2\,. \quad (1)$$

The object of this experiment is to get familiar with the fundamental properties of the interference phenomenon, on one hand, and to get familiar with laser and material properties on the other. Several experiments are suggested.

- Determination of the wavelength λ_0 of the laser source
- Measure of the thermal expansion coefficient of a metal
- Study the magnetostriction phenomenon
- Determine the refraction index of air

II. EXPERIMENTAL SETUP

a) Available equipment

The interferometer is mounted on a stabilized plate with a magnetic base, and contains the following elements (see also LEYBOLD manual available on location):

1 $\mathrm{He-Ne}$ laser light 2 mW source (BE VERY CAREFUL, don't' ever expose your eyes directly to the laser. Permanent damage can occur.
1 base plate
2 lenses of focal distances $\mathrm{f = +5\ mm}$ et $\mathrm{f = +50\ mm}$, 1 beam splitter, 2 precisely adjustable mirrors, 1 mirror for redirecting the beam towards the screen.

A range of accessories (for the corresponding figures, see LEYBOLD documentation):

A) 1 precise micrometric screw to adjust the distance of one mirror. One rotation of the screw moves the mirror by $0.5\ \mathrm{mm}$.

B) 1 thermal expansion measurement mechanism (LEYBOLD Fig. 13). It's made of:
i) One eating body in the shape of a coil
ii) A small mirror that can be attached to the end of available the samples
iii) One thermal probe
iv) One Power supply

C) 1 equipment dedicated to the study of magnetostriction (LEYBOLD Fig. 14). It has:
i) One coil dedicated to generating a magnetic field
ii) The same mirror and power supply as in B).

D) 1 equipment to measure the refraction index of air (LEYBOLD Fig. 8). It's made of one closed chamber connected to a manual pump and a pressure gauge.

b) Setting up the interferometer and fine-tuning

Place the mask corresponding to the Michelson interferometer on the base plate. Put the magnetic bases with the correct optical elements in the designated places (see fig. 1) Avoid touching the lenses mirrors or BS. If necessary, clean the elements with fine alcohol.

To align the interferometer and get parallel interference fringes, proceed as follows:

i) Remove the lenses L_1 and L_2 as well as the BS from their positions, and adjust the mirror M_1 so that it reflect the beam precisely onto the opening. It is **FORBIDDEN because dangerous to expose your eye directly to the light** while adjusting (irreversible damages can occur).

ii) Place the L_1, L_2 and

BS back in, and make sure to keep the laser aligned without touching the mirror M_1. Place the BS at $45°$ in order to split the beam into two beam as orthogonal as possible to one another. Adjust the 2nd mirror M_2 to send the beam back on the beam splitter.

iii) Adjust the interferometer's mirrors using the small screws in order to superimpose both reflections. The outgoing beam is reflected on the mirror M_3, and projected on the screen. If the interferometer is well adjusted, you should see interference patterns. Note that sometimes, we add a diverging lens between the interferometer and the screen, to increase the size of the image. Here, it isn't necessary, since the screen is already far enough.

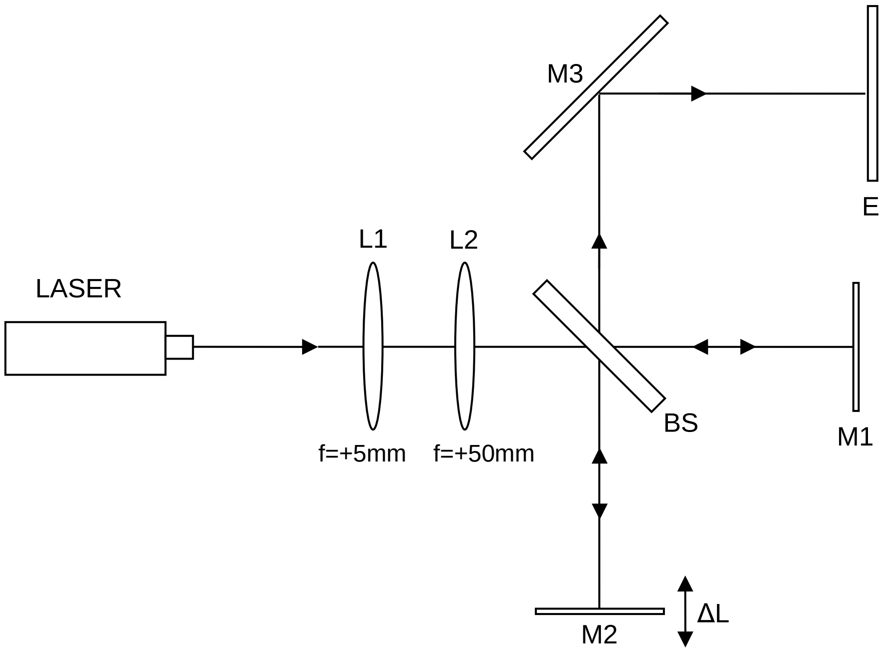

Fig. 1: Setup of the Michelson interferometer

SUGGESTED EXPERIMENTS

Qualitative observations:

Adjust the interferometer in order to get circular or elliptic interference fringes.

1) Test the sensitivity of the setup by pushing down slightly on the table. Interpret your observations.
2) Using a lighter, introduce a small bubble of gas in one of the optical paths $\mathrm{T_r}$ or $\mathrm{T_t}$. Explain your observations.
3) Verify the regularity of a piece of glass by placing it into one of the two optical paths. Interpret the observed image when moving the glass around perpendicularly to the laser beam.

Perform the following measurements after setting up the interferometer for parallel fringes:

4) Determine the wavelength λ_0 of the laser source. Move the mirror $\mathrm{M_2}$ by ΔL using the micrometric screw, and count the number of fringes that pass by. Use formula (1) in order to determine the wavelength of the source.

5) Measure the thermal expansion coefficient of 2 metallic cylinders. By definition, the linear thermal expansion coefficient α of a solid is the ratio of the length variation for a temperature increase of 1 $^\circ\mathrm{C}$ divided by its length at 0 $^\circ\mathrm{C}$. Therefore, if the length at 0 $^\circ\mathrm{C}$, it's length at T °C, l_T, is given by:

$$l_T = l_0(1+\alpha T).$$

Set up the system shown in figure 2 (see also fig. 13 LEYBOLD). Place the accessory B instead of the mirror M1. Adjust the interferometer in order to get parallel fringes. Connect the heating body to the power supply, and place the thermal probe in the sample. In order to be sure that the sample is heated uniformly, heat it up very slowly (approx. 5 fringes/min). Heat the cylinder, and measure the temperature variation for the fringe number N =10, 20, 20, …, 100

6) **Magnetostriction**. Magnetostriction Is the property of certain metals and alloys to change dimension under the influence of a magnetic field.

We suggest evaluating the length of the steel cylinder under the action of a magnetic field $\boldsymbol{B}$. The value of B can be determined approximately according to the formula:

$$B = \frac{\mu_0 N_s I}{L}$$

where $\mathrm{N_s}$ is the number of turns of the coil, I the applied current and L its length. Determine $\Delta l/l$ (l = length of the metal rod).

Prepare the set up (item C) indicated in Fig. 14 of the manual, and place it in a position identical to that described in point 5). Adjust the device in order to have parallel fringes and apply the magnetic field B. It's important for the temperature of the rod to remain as constant as possible. Therefore, only apply the current for short periods of time. Measure the current for N =1, 2, …, 10

7) Determine the refraction index of air in normal conditions, n_0. Introducing a gas of refraction index n in a cavity of length l, placed in the optical path $\mathrm{T_r}$ or $\mathrm{T_t}$ will slow down the light and cause a phase shift equivalent to $\Delta L = 2l(n-1)$. One can therefore observe the number of fringes passing by: $N = [2l(n-1)]/\lambda_0$. By differentiating both sides of this equation with respect to the gas pressure p, we get:

$$\frac{dN}{dp} = \frac{2l}{\lambda_0}\frac{dn}{dp}$$

For a gas, $(n-1)$ is proportional to the density ρ and for an ideal gas $\rho \sim p/T$ therefore $(n-1) = (n_0-1)(pT_0/p_0T)$ where T_0 = $273\ \mathrm{K}$ and p_0 = $101325\ \mathrm{Pa}$. By differentiating with respect to pressure, we get:

$$\frac{dn}{dp} = \frac{n_0-1}{T}\frac{T_0}{p_0}$$ and finally: $$n_0 - 1 = \frac{dN}{dp}\frac{\lambda_0}{2l}\frac{p_0}{T_0}T$$

For this experiment, adjust the interferometer as explained in 4) and place the vacuum chamber in one of the optical paths (accessory E, fig. 8). Compress the air using the piston, and wait for the equilibrium to be reached. Then, slowly let air back out using the microvalve. Write down the number N of fringes that go by as a function of the pressure p indicated by the pressure gauge. Plot $N = N(p)$ and determine dN/dp. Calculate n_0, compare the result with the values found in tables, and discuss the possible sources of error.

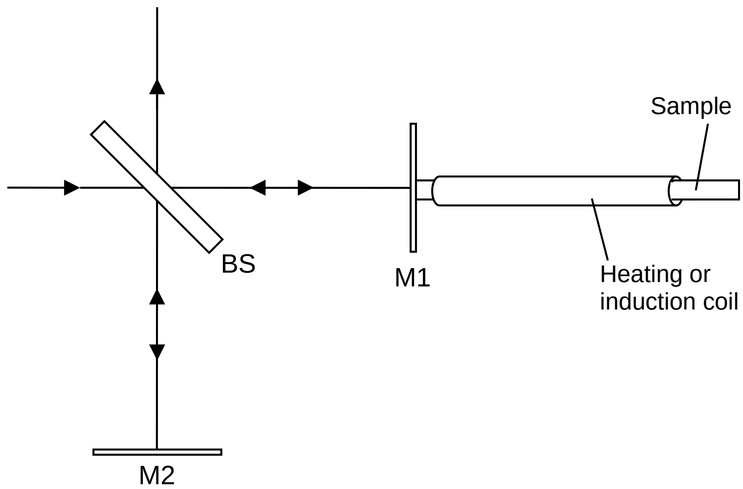

Fig. 2 : Experimental setup for B) and C)

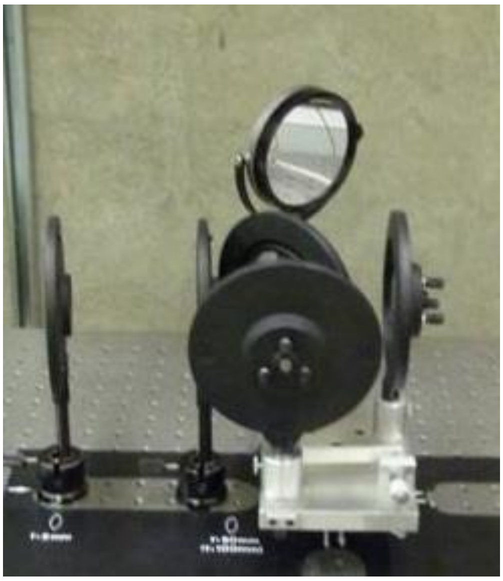

Fig. 3 : Image of the optical elements of the Michelson interferometer.