Determination of Index of Refraction of Gases by an Interferometer

Måns Bermell (mabe0395@student.umu.se)
Joar Svartholm (josv0150@student.umu.se)

December 5, 2017

Abstract

Non-invasive measurement techniques / v1.0
Supervisor: Thomas Hausmaninger

1 Introduction

2 Theory

Light propagates through a medium at a lower velocity than in vaccum. This is described by the index of refraction of the medium

$$n = \frac{c_0}{v}, \tag{1}$$

where c_0 is the speed of light in vaccum and v is the velocity in the medium[1]. By this one can define the optical path length (OPL) as the length the light experiences, that is if the light propagates through a medium of length L and refractive index n, then the OPD will be

$$\text{OPD} = nL.$$

The refractive index is thus a measure of how dense a material is and must therefore be proportional to the pressure. Namely by increasing the pressure P from vaccum, then

$$n - 1 = \alpha \frac{\Delta P}{P_{atm}}, \tag{2}$$

where P_{atm} is the atmospheric pressure and α is the proportionality constant. Note thet since P is measured from vaccum then $\alpha = n - 1$ at atmospheric pressure.

2.1 The Michelson Interferometer

A Michelson interferometer consists of a laser beam being splitted into a reference leg L_1 and a signal leg L_2. The beams are then reflected back and reassembled at a sensor. A schematic sketch of this is found in Fig. 1. If the beams are aligned correctly they will interfere with eachocher and constructive interference will occur if

$$\text{OPD} = N\lambda, \tag{3}$$

where OPD is the optical path difference between the legs, N is an integer and λ is the wavelength of the light.

2.2 Method

If a gas chamber of length d is put on the sensor leg as is shown in Fig. 1 the the OPD can be found as

$$\mathrm{OPD} = 2\mathrm{OPL}_{L_2} - 2\mathrm{OPL}_{L_1} = 2nd + \mathrm{const.} \tag{4}$$

Using the interference condition Eq. (3) this can be reduced to

$$N\lambda = 2nd + \mathrm{const.}.$$

Instead of counting the absolute number of interference maxima, called fringes, one can count the number of fringes that appear when changing the refractive index of the sample. This can then be rewritten as

$$\Delta N\lambda = 2d\Delta n. \tag{5}$$

If one measures this from vaccum one can make us of Eq. (2) in Eq. (5) and obtain

$$\Delta N = \frac{2d\alpha}{\lambda P_{atm}}\Delta P. \tag{6}$$

Thus, by increasing the pressure of a gas from vaccum and counting how many fringes that has passed a sensor one can find the refractive index from the slope of Eq. (6) and α.

3 Experimental setup

The experimental setup used to measure the index of refraction for various gases is illustrated in Fig. 1. The HeNe-laser beam is divided into two legs, reference leg L_1 and signal leg L_2 via a beam splitter (BS). The beam travelling down the signal leg is transmitted through a gas chamber made of acryllic glas, with inner length $d = 100(1)$ mm. And then reflected via a mirror back the same way where it is reflected on the beam splitter where it coincides with the other part which has been reflected in L_1. The recombined laser beam shines through a small apperature in order to elliminate laser beams due to unwanted reflections. It then reaches a lens which diverges the laser beam in order to increase the resolution. A photodiode is mounted after the lens in order to pick up any changes of incident intensity of the combined laser beam. In order to eliminate ethalons inside the gas chamber, it was mounted at an angle relative the incident laser beam.

If the two legs are aligned propertly, an interferance pattern will emerge on the photodiode. If vaccum is created inside the gas chamber and then a steady flow of gas added, the optical path will increase. An interferance pattern (fringes) on the photodiode will start to move continuously. By measuring the intensity changes

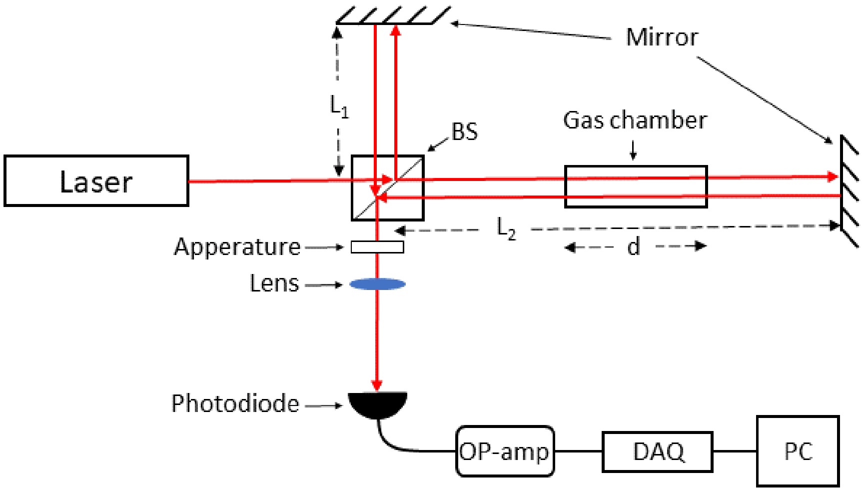


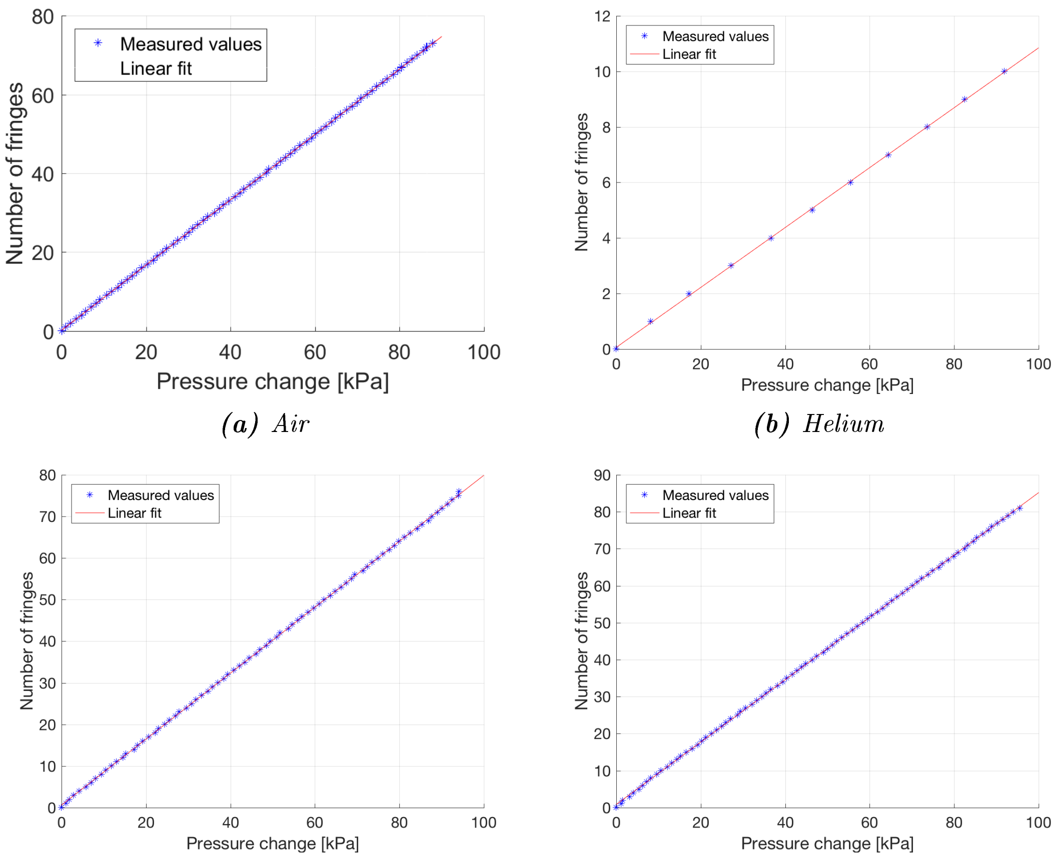
Figure 1 – *Experimental setup.*

4 Results and discussion

The number of fringes was plotted against the pressure change for the different gases and is found in Fig. 2. As one can see in the figures all gases showed a linear relation which was expected. When comparing Fig. 2b with the others the number of fringes is a lot lower than for the others. This means that the index of refraction must be a lot lower for this and the relative error will probably be larger.

Table 1 – *Fitting parameters for the measured values in Fig. 2. Linear fit on the form $y = \alpha x + \beta$.*

	α	β
Air	0.828(1) kPa^{-1}	0.16(6)
Helium	0.108(1) kPa^{-1}	0.06(5)
Argon	0.793(1) kPa^{-1}	0.61(5)
Nitrogen	0.843(1) kPa^{-1}	0.86(5)



(a) *Air* ***(b)*** *Helium* ***(c)*** *Argon* ***(d)*** *Nitrogen*

Figure 2 – *Number of fringes and pressure change for the different gases with linear fits. Fitting parameters are found in Tab. 1*

References

[1] Nordling, C., 2006. *Physics Handbook for Science and Engineering.*