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Experimental Optics

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Michelson-Interferometer

Contents

1 Overview

In an interferometric setup (usually electromagnetic) waves are superimposed to extract information – either about the waves itself or about some kind of matter the waves were interacting with. This applies e.g. to autocorrelation of short laser pulses, but also to spectroscopy, e.g. the frequently used Fourier-transform Infrared (FTIR) spectrometer in chemistry. Further applications are e.g. stress/strain measurements and surface profiling, velocimetry and optometry.

The history of interferometers began in 1881 with a setup created by Albert A. Michelson (for which this setup is named) which in 1887 resulted in the Michelson–Morley experiment (performed together with Edward W. Morley). They measured the speed of light in perpendicular directions, in order to figure out the influence of the so-called "luminiferous aether". As they found no difference in speed of light at right angles, this was a first strong evidence against the aether theory, eventually inspiring to the theory of special relativity. [1]

Another important historical achievement is the definition of the meter to be equal to 1,650,763.73 wavelengths of the orange-red emission line of the krypton-86 atom in vacuum (Eleventh General Conference on Weights and Measures in 1960). But it is already outdated because in 1983 the seventeenth General Conference on Weights and Measures replaced the definition of the meter with its current definition: "The meter is the length of the path travelled by light in vacuum during a time interval of 1⁄299,792,458 of a second."

The basic Michelson interferometer setup uses any kind of beam splitter to divide one beam of light into two beams, each of them back-reflected to the beam splitter and recombined and directed to the fourth arm where any kind of detector is placed. One arm of the interferometer may have different length or contain some material under test.

In this experiment the students should learn about basic aspects of laser security (see Chapter 2), the basic principles of interference (see Chapter 3) as well as the components (see Chapter 4) and their handling, alignment and measurement techniques (see Chapter 5) of this basic Michelson interferometer system.

2 Safety issues

The laser system which will be built in this experiment is classified according to DIN (Deutsches Institut für Normung = German Institute of Standards) IEC 60825 as a Class 3R Laser. A Class 3R laser is considered safe if handled carefully with restricted beam viewing. With a class 3R laser, the maximum permissible exposure (MPE) can be exceeded, but with a low risk of injury. Visible continuous lasers in Class 3R are limited to 5 mW. It is recommended to use the appropriate laser safety goggles in addition with protective shields against laser stray light caused by additional optics used for the measurements.

- Never look directly at the beam or its reflections or point it towards other people.
- Please wear appropriate laser safety goggles at all times when in a lab with lasers.
- Remove all reflecting objects attached to your hands/wrists (e.g. rings, watches, bling etc.)
- Never insert or remove an optical element from the rail unless the laser beam is blocked either mechanically or by shutting down the power supply.
- Never tilt elements of the setup or alignment discs such that the light reflected from its surface might be directed towards you or other people in the lab.

To fulfill the laser safety precautions insure that the laser beam is adequately limited and not leaving the workspace! For example use the screen (Part 9) or the target screen (Part 11) mounted in a holder (see Figure 5, page 11).

3 Theoretical background

A wave is defined as an oscillation (repetitive variation, typically in time) of a physical quantity u around fixed positions accompanied by a transfer of energy from one point to another, in that way able to travel through a medium. The following table compares some equations describing oscillations and waves:

	Oscillation	Wave	
Differential equation	$\frac{\mathrm{d}^2u}{\mathrm{d}t^2} = -c \cdot u$	$\frac{\partial^2 u}{\partial t^2} = c^2 \cdot \frac{\partial^2 u}{\partial x^2}$	(1)
Solution	$u(t) = A \cdot \cos(\omega t + \varphi)$	$u(t,x) = A \cdot \cos(kx - \omega t + \varphi)$	(2)

This physical quantity might also be a dimension in space, c is a positive constant, ω is the angular frequency, t is the time, k is the wavenumber and x is a spatial coordinate in the direction of the wave propagation. The wave equation (1) is an important second-order linear partial differential equation.

3.1 Interference and coherence

To *interfere*, two (or more) waves superpose to form a resultant wave, meaning the mathematical addition of these wave functions. Its limiting cases are constructive and destructive interference. But interference always occurs, even when the resulting wave is complicated or almost unchanged (please see Figure 1).

Interference usually refers to the interaction of coherent waves, meaning the same frequency and constant phase difference. *Coherence* describes all properties of the correlation between physical quantities of interacting waves and is an ideal property, that enables stationary (i.e. temporally and spatially constant) interference.

Spatial coherence is the cross-correlation between two points in a wave front at the same time. E.g., if in Young's double-slit experiment, the space between the two slits is increased, the coherence dies gradually and finally the fringes disappear. Significant interference defines the diameter of the coherence area, A_c [2].

Temporal coherence characterizes the ability of a wave to interfere with a copy of itself delayed by a certain time τ. At $\tau = 0$ there is perfect coherence. If the delay increases, and the visibility of the interference decreases significantly due to changes in frequency and phase, the coherence time τ_c is reached. The distance travelled by the wave during the coherence time is defined as the coherence length l_c, and it is very important not to mix it up with the above mentioned coherence area A_c. Both coherence time and length are connected to the spectral width in wavelength $\Delta\lambda$ or in frequency Δf of a light source with a central wave length λ by the following equation:

$$\tau_c = \frac{1}{\Delta f} = \frac{\lambda^2}{c\Delta\lambda} \qquad (3)$$

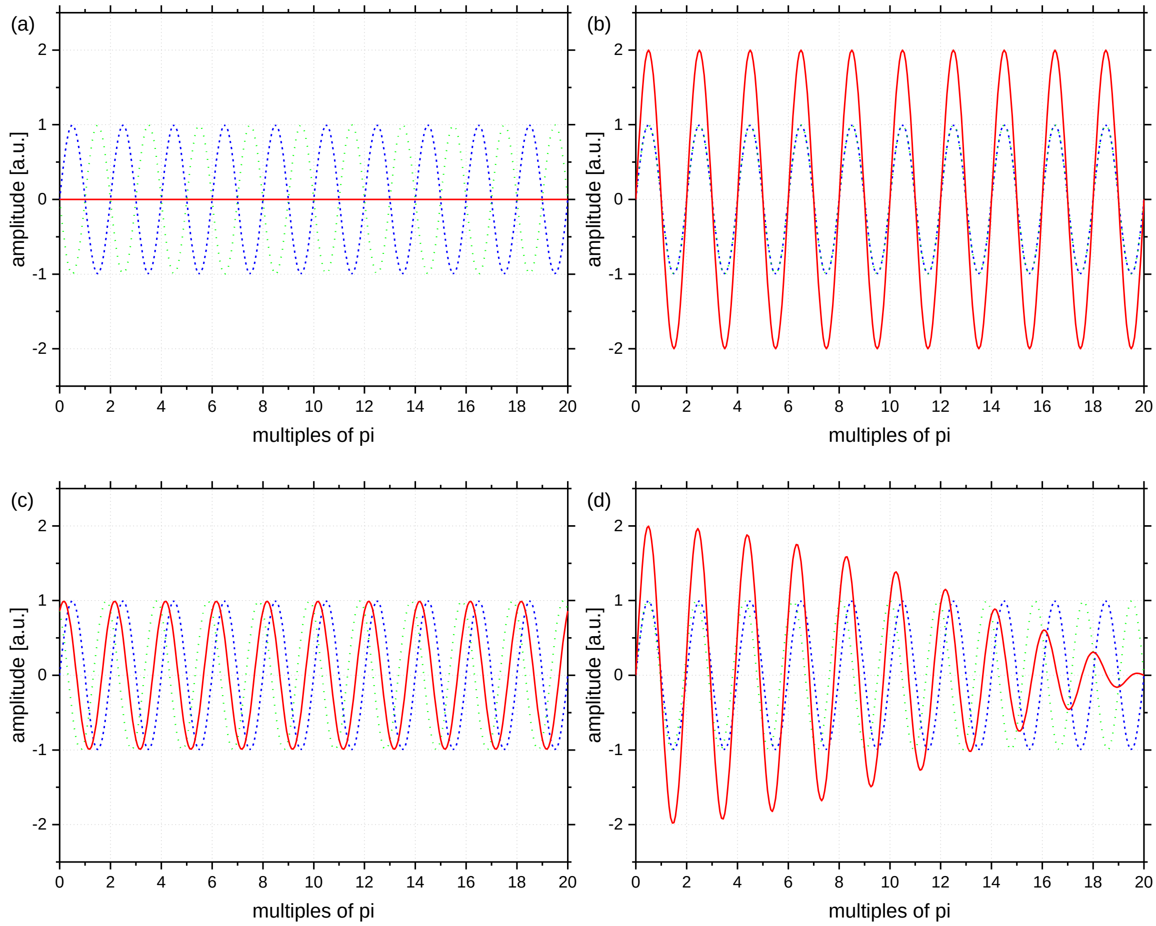


Figure 1: Different characteristic interference patterns of two incident waves (green and blue) and the resulting wave (red). The limiting cases are destructive (a) and constructive (b) interference, but also a resulting wave which is identical to the incident waves might occur (c). For one wave having a larger wavelength the interference pattern fade out.

3.2 Interference of light

The peculiarity of electromagnetic waves is that they can also propagate in the absence of a medium. They consist of synchronized oscillations of electric and magnetic fields, which are perpendicular to each other and perpendicular to the direction of energy and wave propagation (transverse wave). The electric field of light can be described as follows (derivation based on [3]):

$$\vec{E}(t,x) = \vec{E}_0 \cdot \cos(\omega t - kx) \tag{4}$$

Here $\vec{E}_0$ is the maximal amplitude of the electric field.

The amplitude is split fifty-fifty at the beam splitter $\vec{E}_{0,A} = \vec{E}_{0,B} = \frac{1}{2}\vec{E}_0$ (here the subscripts A and B refer to the different optical paths of the beam, please also refer to Figure 2) and then recombined at the projection screen (subscript P), where each of the waves can be described as:

$$\vec{E}_{P,i} = \frac{1}{4}\vec{E}_0 \cdot \cos(\omega t - \varphi_i) \tag{5}$$

The index i can either be A or B and φ is the phase difference correlated to the optical path the wave has travelled. Please note, that each wave – backreflected from the mirror – is again split at the beam splitter: one part going to the projection screen, one back to the laser source (see Figure 2).

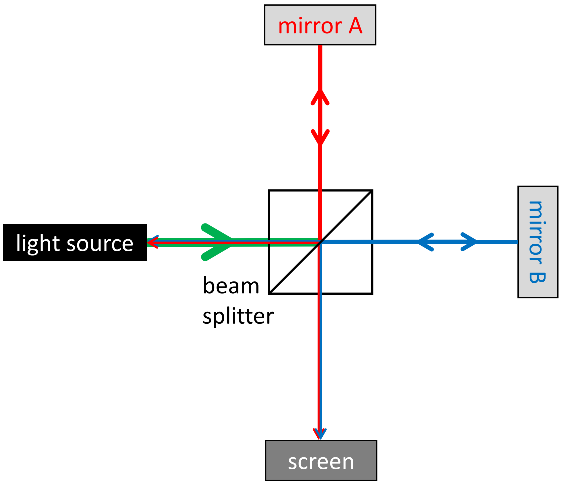


Figure 2: Schematic of the Michelson Interferometer setup showing the relationship between the intensities of the incident laser beam, the two beams transmitted/reflected to the mirror, those parts recombined on the screen arm and back-reflected to the light source.

The intensity at the projection screen can be obtained as follows:

$$I_P = c \cdot \epsilon_0 \cdot \left|\vec{E}_{P,A} + \vec{E}_{P,B}\right|^2 \tag{6}$$

With $E = \left|\vec{E}\right|$ one can rewrite the above equation to:

$$I_P = \frac{1}{4} \cdot c \cdot \epsilon_0 \cdot E_0^2 \cdot [\cos(\omega t + \varphi_A) + \cos(\omega t + \varphi_B)]^2 \tag{7}$$

As the light period T is very short (in the order of femto seconds), only the time averaged intensity can be observed on the screen. It can be obtained via an integration of equation (7) by ωt [4]:

$$\langle I_P \rangle = \frac{1}{4} \cdot c \cdot \epsilon_0 \cdot E_0^2 \cdot [1 + \cos(\varphi_A - \varphi_B)] \tag{8}$$

The phase difference $\varphi_A - \varphi_B = \Delta\varphi$ is correlated to the optical path difference $\Delta x = x_A - x_B$ by the wave number $k = \frac{2\pi}{\lambda}$, which leads to the new formulation of equation (8)

$$\langle I_P \rangle = \frac{1}{4} \cdot c \cdot \epsilon_0 \cdot E_0^2 \cdot \left[1 + \cos\left(\frac{2\pi}{\lambda}(x_A - x_B)\right)\right] \tag{9}$$

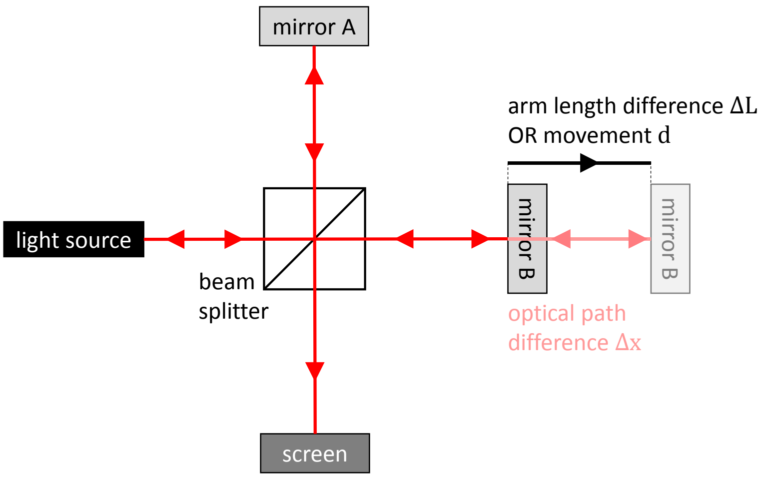


Figure 3: Schematic of the Michelson Interferometer setup showing the relationship between arm length difference and optical path difference.

Now we should have a closer look at the sketch (see Figure 3) to determine some meaningful value for the x. From the beam splitter the beam A goes to the fixed mirror and back, than to the screen. For beam B it is likewise, despite that it goes to the translating mirror. So twice the difference in the arm length $\Delta L = L_A - L_B$ (here L is the distance from the center of the beam splitter to the mirror) corresponds to the optical path difference Δx, because the light travels towards the mirror and back to the beam splitter. Equation (9) can now be rewritten to:

$$\langle I_P \rangle = \frac{1}{4} \cdot c \cdot \epsilon_0 \cdot E_0^2 \cdot \left[1 + \cos\left(\frac{4\pi}{\lambda}(L_A - L_B)\right)\right] \tag{10}$$

So we can see that maxima and minima (fringes and extinctions) will occur when the following conditions are met:

Maximum $\quad \Delta L = \frac{1}{2} \cdot m \cdot \lambda$

Minimum $\quad \Delta L = \frac{1}{2} \cdot \left(m + \frac{1}{2}\right) \cdot \lambda$

$m = 0, 1, 2, \ldots$

As you change the length of path B you will change the phase of the two beams relative to each other. When this translation corresponds to half of the wavelength (or any integer multiple thereof) maxima will be seen in accordance to the cosine behavior of equation (10). Conversely, minima will be seen when the displacement causes the beams to be out of phase by 180°.

3.3 Applications

This correlation between Δx (and ΔL, respectively) to the wavelength λ can be used for several measurements with the basic Michelson interferometer setup (please see Chapter 4.1), one example is the measurement of a distance d the translating mirror has moved. For an entire fringe/extinction event Δx changes by a distance equal to the wavelength of the light, and d changes by a distance equal to half the wavelength (please also refer to Figure 3). The moved distance d for a certain number of fringes N crossing the detector is calculated as follows:

$$d = N \cdot \frac{\lambda}{2} \tag{11}$$

In case the velocity $v = \frac{d}{\Delta t}$ of the moved mirror needs to be determined, the distance according to equation (11) has to be connected to the time interval Δt in which the fringe/extinction events occurred.

$$v = \frac{N}{\Delta t} \cdot \frac{\lambda}{2} \tag{12}$$

It is important that in this case λ is the wavelength in the medium where the movement takes place. So the vacuum wavelength has to be devided by the refractive index n of the medium, which can be approximated for air by the so-called Edlen function:

$$n = \frac{p[hPa] \cdot 293\ K}{1013.25\ hPa \cdot T[K]} \tag{13}$$

Both velocity and distance measurements require the countability of the fringe events, meaning that the maxima and minima of the intensity are clearly distinguishable. One measure for that is the visibility function, which is defined as follows:

$$M = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \tag{14}$$

I_{max} and I_{min} are the extreme values of the intensity of the laser light observed on the screen. With this function also called interferometric visibility it is even possible to give a definition of the coherence time τ_c (please also see page 5). If the fringe visibility has dropped to $\frac{1}{e} \approx 37\ \%$, the coherence time has been reached [5].

Another prerequisite for macroscopic distance measurements is the reliable counting of the fringe events. Within the setup of the technical Michelson interferometer this is done by a device called Laser interferometer controller (LIC), which processes the signal from a detection unit and automatically counts the fringe events. Another feature of the LIC is the ability to determine the direction of the movement. For a better understanding the detailed beam paths of the technical Michelson interferometer will be explained here (please also refer to Figure 4).

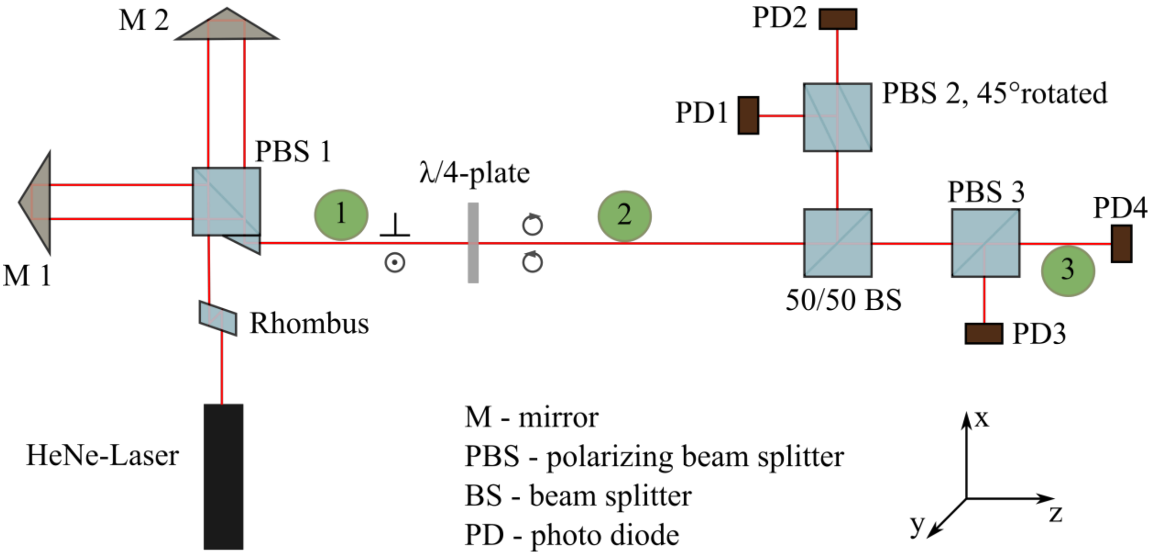


Figure 4: Experimental setup of the technical interferometer. The positions for the calculation steps are represented by the green circles.

After the Michelson interferometer part (before the $\frac{\lambda}{4}$-plate) the two recombined beams are linearly polarized and orthogonal to each other. Consequently no interference pattern can be seen at this point. With $\Delta\varphi$ representing the relative phase difference between the two interferometer arms, the electric field at "position 1" is:

$$\vec{E_1} = \begin{pmatrix} E_x \\ E_y e^{i\Delta\varphi} \end{pmatrix} \tag{15}$$

In the following the orthogonal polarization direction of this field is as the reference coordinate system, with z-axis as the propagation, x-axis as horizontal and y-axis as vertical direction. In order to calculate how different optical components in the setup affect the incident electric field, the Jones-Matrix formalism (please refer to the literature, e.g. [6]) can be used. The following Jones matrices for the optical components are of interest for this setup:

PBS (horizontal transmission)	PBS (vertical transmission)	Phase retarder
$\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix}$	$\begin{pmatrix} e^{-i\varphi_x} & 0 \\ 0 & e^{-i\varphi_y} \end{pmatrix}$

All optical components (polarizing beam splitters, phase retarders etc.), which modify the incoming beam depending on its polarization direction have to be calculated in their inherent coordinate system. In order to mathematically achieve the transfer from one coordinate system to the other, a rotation matrix is used, where θ represents the rotation angle:

$$\begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \tag{16}$$

In order for the technical interferometer to work properly, the fast axis of the quarter wave plate ($\varphi = \frac{\pi}{2}$) needs to be tilted to $\theta = 45°$ to the horizontal axis. The effect by the quarter wave plate can be calculated as follows:

$$\begin{aligned}
\overrightarrow{E_2} &= \begin{pmatrix} \cos 45° & -\sin 45° \\ \sin 45° & \cos 45° \end{pmatrix} \begin{pmatrix} e^{+i\frac{\pi}{4}} & 0 \\ 0 & e^{-i\frac{\pi}{4}} \end{pmatrix} \begin{pmatrix} \cos(-45°) & -\sin(-45°) \\ \sin(-45°) & \cos(-45°) \end{pmatrix} \overrightarrow{E_1} \\
\overrightarrow{E_2} &= \frac{1}{4} \begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} 1+i & 0 \\ 0 & 1-i \end{pmatrix} \begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix} \begin{pmatrix} E_x \\ E_y e^{i\Delta\varphi} \end{pmatrix} \\
\overrightarrow{E_2} &= \frac{1}{2} \begin{pmatrix} [1-i]E_x + [1+i]E_y e^{i\Delta\varphi} \\ [1+i]E_x + [1-i]E_y e^{i\Delta\varphi} \end{pmatrix}
\end{aligned} \tag{17}$$

This result corresponds to right circular and left circular polarized light, respectively, at “position 2” (refer to Figure 4). Since these two polarizations are still orthogonal, no interference can be observed after the quarter wave plate.

In order to understand what happens at the beam splitter cubes, one example is calculated here to see the intensity incident on the photodiode PD4. The beam cube is oriented according to the reference coordinate system. The electric field at “position 3” (refer to Figure 4) is:

$$\begin{aligned}
\overrightarrow{E_3} &= \frac{1}{2} \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} [1-i]E_x + [1+i]E_y e^{i\Delta\varphi} \\ [1+i]E_x + [1-i]E_y e^{i\Delta\varphi} \end{pmatrix} \\
\overrightarrow{E_3} &= \frac{1}{2} \begin{pmatrix} [1-i]E_x + [1+i]E_y e^{i\Delta\varphi} \\ 0 \end{pmatrix}
\end{aligned} \tag{18}$$

The intensity incident on the photodiode can be calculated as follows, assuming $E_{x/y} = E_{x/y}^*$ and defining $E_x E_y = I_{xy}$:

$$\begin{aligned}
I_3 &\propto \vec{E} \cdot \vec{E}^* \\
I_3 &\propto \frac{1}{4} \left([1-i]E_x + [1+i]E_y e^{i\Delta\varphi} \right) \cdot \left([1+i]E_x + [1-i]E_y e^{i\Delta\varphi} \right) \\
I_3 &\propto \frac{1}{4} \left(I_x + I_y - 2I_{xy} \cdot \sin\Delta\varphi \right)
\end{aligned} \tag{19}$$

The results indicates, that a sinusoidal interference pattern ($\propto -\sin\Delta\varphi$) can be detected when $\Delta\varphi$ is continuously changed with time (movement of the translation mirror). Calculations of the intensity incident on the other photodiodes will result in $\cos$, $-\cos$ and $\sin$ patterns for continuous movements.

4 Setup and equipment

4.1 Basic Michelson interferometer setup

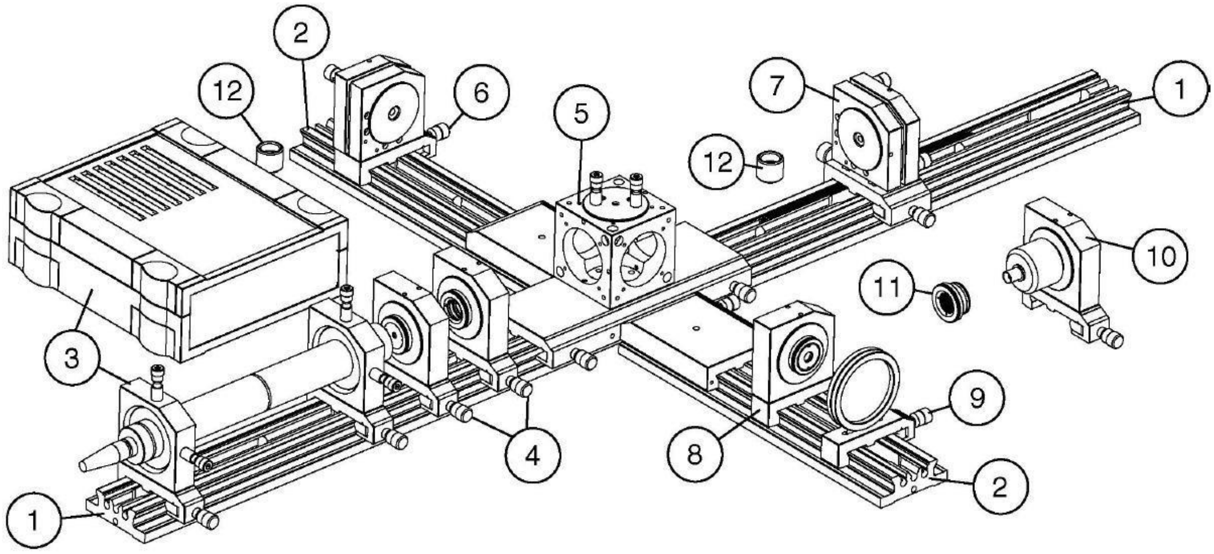


Figure 5: Experimental setup of the Michelson Interferometer [7].

1. Flat rail 500 mm with scale
2. Flat rail 300 mm with scale
3. HeNe-Laser tube with power supply [7]:

   Average Output power: $P = 2.5\ mW$
   Central wavelength (vacuum): $\lambda = 632{,}991\ nm$
   Longitudinal mode spacing: $\Delta f = 820\ MHz$

4. Laser beam expansion optics [7]:

   Expansion lens: $f_1 = -10\ mm$
   Diverging lens: $f_2 = 80\ mm$

5. Beam splitter (50%/50% amplitude division)
6. Plane mirror in adjustment holder on carrier
7. Plane mirror in adjustment holder on carrier with additional translation screw
8. Beam expander lens on carrier
9. Screen on carrier
10. PIN photodetector with BNC cable in holder
11. Crosshair target screen insert

4.2 Technical extension of the Michelson interferometer

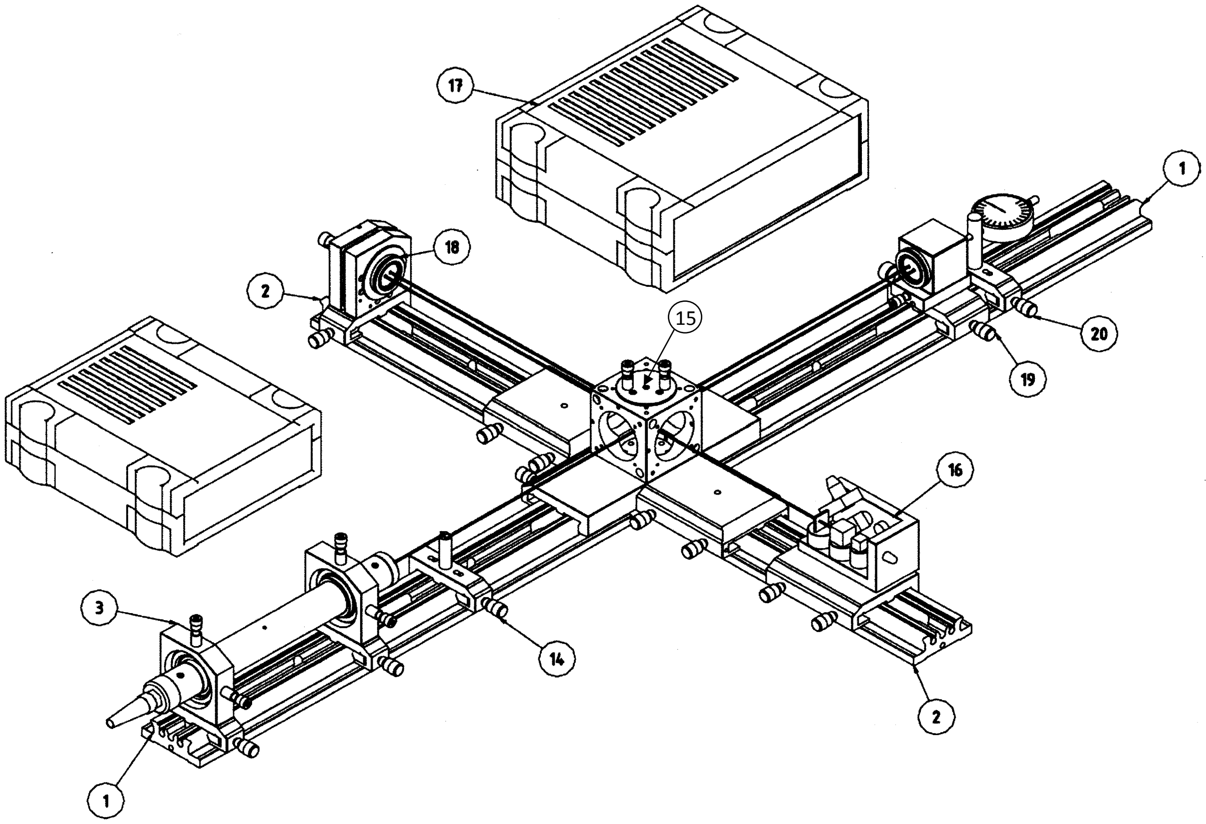


Figure 6: Technical expansion of the Michelson Interferometer [7].

14. Lateral beam displacement optics
15. Polarizing (horizontal & vertical) beam splitter
16. Signal detection unit for sin/cos
17. Laser interferometer controller LIC 1000
18. Corner cube mirror
19. Corner cube mirror on translation stage
20. High resolution (1 µm) dial gauge

5 Goals of the experimental work

5.1 Basic Michelson interferometer

5.1.1 Adjustment

Before starting check if all components are available, in good order and clean. Detailed instructions for the cleaning of optical components will be given during the lab.

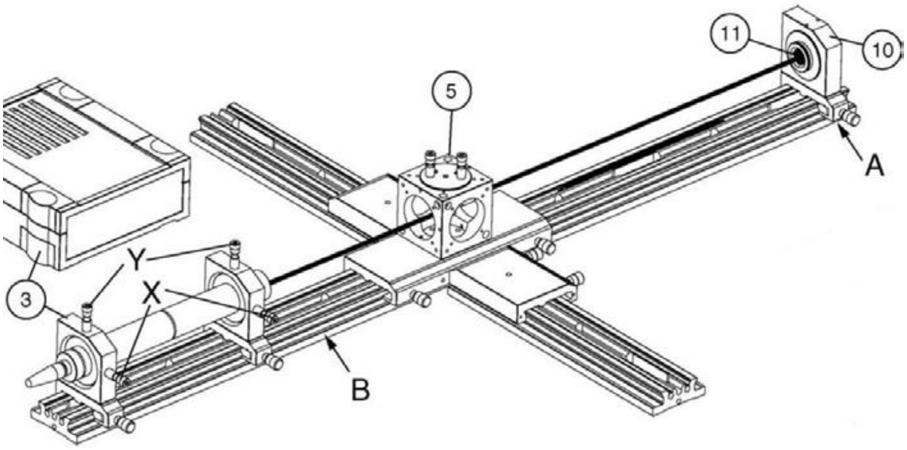


Figure 7: Adjustment of the laser to define the optical axis [7].

The first step is to define the optical axis, i.e. the laser beam has to pass through the beam splitter cube (BSC; Part 5, see Figure 7) parallel to the rail. So first place the holder (Part 10) with the target screen insert (Part 11) in front of the laser source (position B) and adjust the laser so that it hits exactly at the center of the target, using the X- and Y-screws of the front holder of the laser. Afterwards move the target screen to the end of the rail and make the laser hit its center using X- and Y-screws of the rear holder of the laser. Once the laser is adjusted, the optical axis is defined and no further movement of the laser should be done while proceeding with the following adjustment steps.

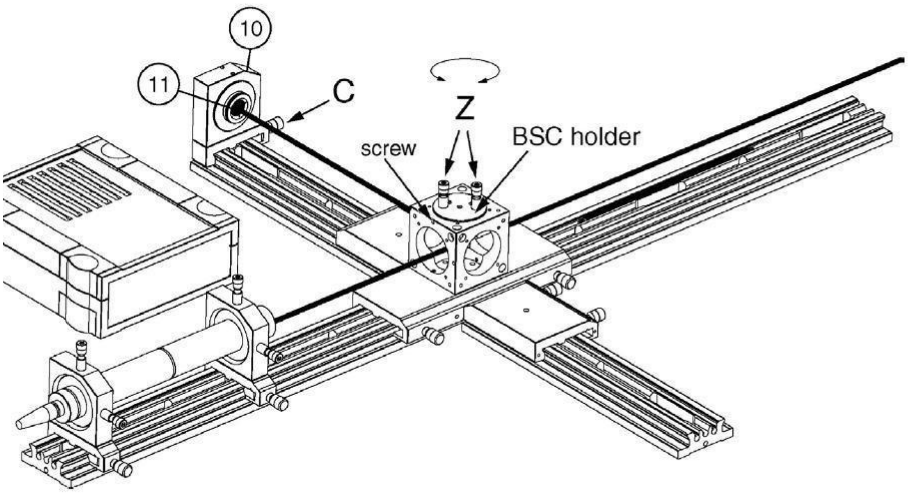


Figure 8: Adjustment of the beam splitter [7].

Next step is to adjust the deflection from the beam splitter (BS) to the reference path of the Michelson interferometer. For this task place the target screen on the reference arm (at position C, see Figure 8). Loose the screw on the side of the BSC (see Figure 8) and rotate it to make the deflection hit the center of the target screen. If you cannot reach the center by rotating the BS, than continue the alignment using the fine adjustment screws Z on top of the BS.

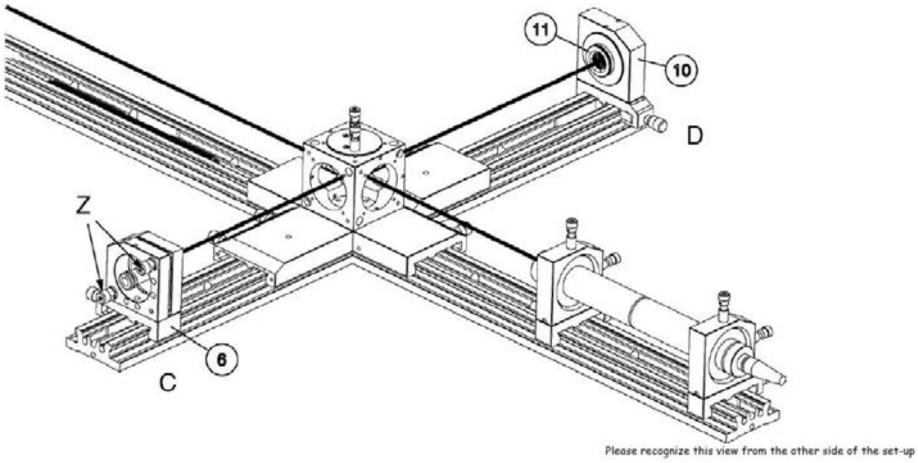


Figure 9: Adjustment of the reference mirror [7].

The next step is the adjustment of the fixed mirror on the reference arm. Place the mirror holder for the fixed mirror (Part 6) with the plane mirror inserted on the reference arm (position C, see Figure 9), the target screen is moved to the opposite side (position D). Make the reflected laser beam hit the center of the target screen by adjusting the tilt of the fixed mirror, using the screws Z on the back side of the mirror holder. Since there are several spots from internal reflections of the beam-splitter, always use the brightest spot for the alignment.

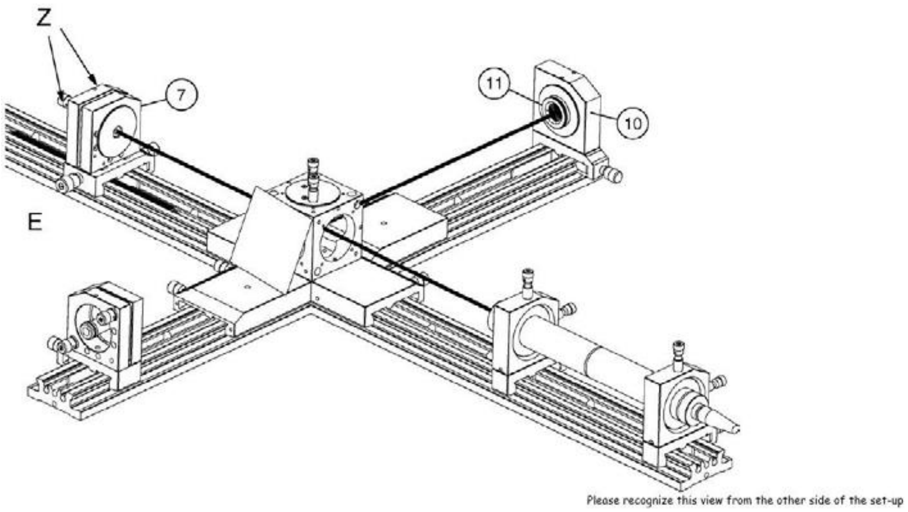


Figure 10: Adjustment of the translation mirror [7].

The next step is the adjustment of the translating mirror on the measurement arm. Place the mirror holder for the translating mirror (Part 7) with the plane mirror inserted on the measurement arm (position E, see Figure 10). The target screen remains in the same position, but the deflection coming from the reference arm has to be blocked (e.g. insert a piece of paper in the beam path, see Figure 10). Again make the reflected laser beam (brightest spot) hit the center of the target screen by adjusting the tilt of the translating mirror, using the screws Z on the back side of the mirror holder.

The last step is the improvement of the visibility of the fringes. Replace the target screen by the projection screen (Part 9). Observe the appearance of the fringes. Some suggested operations:

- Vary the tilt of the fixed and translating mirror and watch how the fringe pattern is changing. Some basics about the fringe formation are shown in Figure 11.

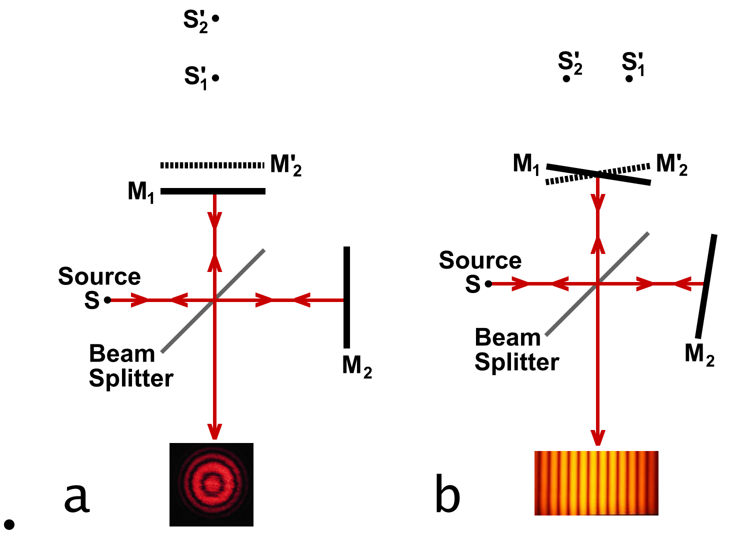
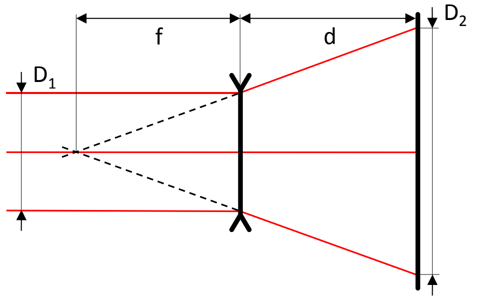


Figure 11: In this schematic Michelson interferometer setup a direct image of the first mirror (M_1) and a reflected image (M_2') of the second mirror can be observed through the beam splitter, which reveal two virtual images of the light source (S_1' and S_2'). For really perfect alignment those virtual images are in a line with the observer, yielding an interference pattern of circles centered on the normal of the mirrors M_1 and M_2', so-called "fringes of equal inclination" (a). If M_1 and M_2 are tilted, the fringes form conic sections (hyperbolas). In that case M_1 and M_2' overlap, the fringes will be straight, parallel, and equally spaced, so-called "fringes of equal thickness" (b) [8, 9].

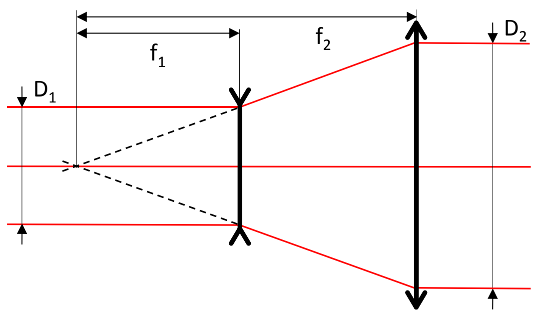
- Use an expansion lens for magnification (please see equation (20) and Figure 12).



$$\frac{D_1}{D_2} = \frac{|f|}{|f| + d} \tag{20}$$

Figure 12: Manification of an expansion lens.

- Use a Galilean telescope for the purpose of magnification (please see equation (21) and Figure 13). Note: the magnification is the same as for the single expansion lens with a screen put in the appropriate distance $d = f_2$, but a Galilean telescope generates parallel beams.



$$\frac{D_1}{D_2} = \frac{|f_1|}{f_2} \tag{21}$$

Figure 13: Expansion of a Galilean telescope.

- Use apertures to block side reflections next to the superimposed brightest spots coming from both the measuring and reference arms.
- Avoid back reflections coming into the laser – they can seriously disturb the further measurements! Take care that the back reflections hit only the laser housing – there might be a slight de-alignment be necessary.

5.1.2 Measurement of the visibility function

The visibility function of an interferometer is defined according to equation (14), page 9. As the intensity of the light cannot be measured directly, in this experiment a PIN photo detector is used to create free electrons ("photo electrons") inside the detector material due to the light that shines on its surface. An oscilloscope measures the voltage of the "photo current". So the maxima and minima of the light intensity lead to maxima and minima in the voltage, U_{max} and U_{min}. Hence (assuming a linear proportionality between intensity and photo voltage), equation (14) can be rewritten to:

$$M = \frac{U_{max} - U_{min}}{U_{max} + U_{min}} \tag{22}$$

For this measurement replace the projection screen by the photo detector unit (Part 10, see Figure 14). Use the BNC cable to connect the photo detector with the oscilloscope. (Detailed instructions for the use of the oscilloscope will be given during the lab. Very important: when taking measurements with an oscilloscope, do not forget to measure the dark and the background voltage!)

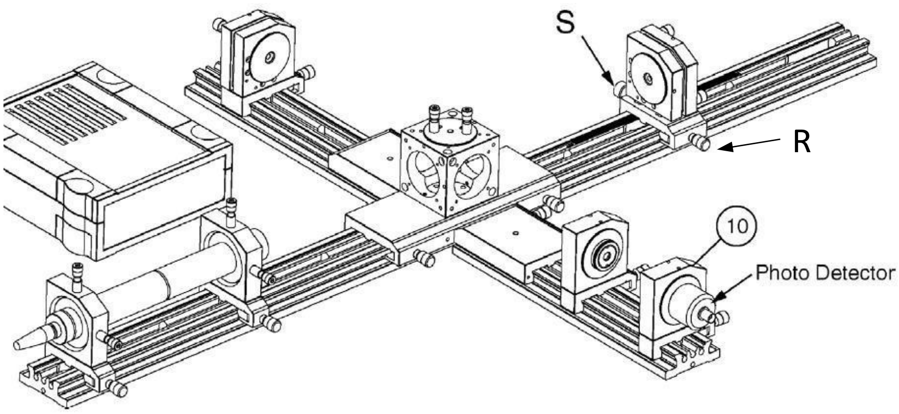


Figure 14: Setup for the visibility measurement with the photodiode [7].

Move the translating mirror to a certain position on the rail (note the mm-readings of the ruler, also for the fixed mirror!) and fix it using screw R. Turn srew S back and forth and note the values for the minimum and maximum voltage displayed on the oscilloscope, when the voltage is oscillating due to the dark and bright fringes crossing the detector. Choose different positions along the rail and carry out the measurement as described above. Finally, calculate the visibility M (using equation (22)) and its error, and plot M versus the optical path difference Δx.

The quality of the result depends strongly on the adjustment state of the setup. Best values are gained if the variation of the fringes always cover the area of the detector as wide as possible.

5.2 Technical extension of the Michelson interferometer

5.2.1 Adjustment

Exchange the previous beam splitter with the prism beam splitter (Part 15). The prism side must face the laser. Add the rhombus lateral displacement optics (Part 14) directly in front of the laser (please also refer to Figure 6, page 12).

Use the target screen (Part 11) to check that the laser beam is going parallel through the BSC (Part 5). The beam should not be in the center of the target, as it has been shifted laterally by about 5 mm by the rhombus, so make sure it does not move position when moving the target along the rail.

Instead of the two plane mirrors, corner cube reflectors are needed now. Remove the plane mirror insert from Part 6 and install the corner cube insert (Part 18). Remove the plane mirror holder (Part 7) from the rail and install the corner cube reflector on its translation stage (Part 19) on the rail.

The two beams reflected back by the corner cubes should superimpose in the beam splitter and be deflected towards the measuring arm by the prism attached to the beam splitter. Check to make the overlap as perfect as possible.

Add the signal detection unit (Part 16) to the measurement arm. The superimposed beams deflected by the prism should enter the center of the input of the signal detection unit. The signals detected on the four photo diodes (for theory please see Chapter 3.3) are transmitted to the Laser Interferometer Controller (LIC, Part 17).

5.2.2 Measurements of length

By specifying the vacuum wavelength of the laser as well as the temperature and pressure of air (please refer to equation (13), page 8), the LIC calculates the distance of the mirror movement as well as the direction of the movement according to the equations given in Chapter 3.3. Place the high resolution dial gauge (Part 20) behind the translation stage of Part 19 (please also refer to Figure 6). Please move the mirror by a certain distance according to the measurement with the dial gauge and compare it with the value obtained by the LIC. Choose five different distances across the measurement range of the dial gauge and measure each distance at least five times. Compare the errors of both methods applied!

5.2.3 Measurements of velocity

Connect the four outputs from the LIC (+sine, –sine, +cosine and –cosine, located on the back side of the device) to the oscilloscope. A sinusoidal pattern can be observed on the oscilloscope when the translating mirror (Part 19) is continuously moved. Measure the time (stop watch) of a constant movement over a certain distance (Note the readings on the dial gauge). Calculate the velocity for the whole movement. Freeze the oscillations displayed on the oscilloscope during this movement (if no evaluable number of fringes is displayed, try to vary your velocity or the time trigger of the oscilloscope). Count the number of fringes and calculate the according distance with equation (11) for each signal. The time trigger of the oscilloscope determines the time for the occurrence of these fringes (detailed instructions will be given during the lab). Calculate the velocity using equation (12). Compare both the values and the errors of the two methods applied!

A Preliminary questions

- What is the wavelength of the laser?
- What is the power of the HeNe laser to be used in the measurements?
- What are the goals of your experiment?
- What is optical interference?
- What is the influence of the coherence of a light source on interference pattern?
- Please calculate the theoretical coherence length of the HeNe laser used in the experiment!
- What is the reason for fringe pattern?
- What are the conditions for maximum and minimum intensity?
- What is the number of fringes crossing the center when the mirror is moved by a distance d? How a velocity can be derived?
- Describe how you would accomplish the alignment of laser to the optical axes and the alignment of the mirrors.
- What is the dark and the background voltage of an oscilloscope and how can you measure them?
- Calculate the magnification factor of the Galilean telescope used in this experiment!

(To be answered within the preliminary talk!!!)

B Final questions

- Why does the reflected beam getting into the laser cavity cause instability of the intensity?
- Which components can be used to improve the visibility of the fringes? What are their impacts?
- What would be the influence of an aperture placed in front of the detector having aperture less than the size of detector's active area? Does the contrast function increase or decrease?
- How the measurement range and the measurement accuracy are usually connected? How is this connection for the velocity measurement at the Michelson Interferometer?

(To be answered within the discussion part of the report!)

References

Quotations

[1] https://en.wikipedia.org/wiki/Michelson%E2%80%93Morley_experiment

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[3] Wolfgang Demtröder, *Experimentalphysik 2 : Elektrizität und Optik* (Springer, Berlin, 2013), p. 306. http://dx.doi.org/10.1007/978-3-642-29944-5

[4] Thorlabs Inc., *User Guide EDU-MINT1/M Michelson Interferometer Kit* (Version November 2016). https://www.thorlabs.de/drawings/6b43484641542214-6BF9AB1C-5056-2306-D9133DC5271451E9/EDU-MINT1_M-EnglishManual.pdf

[5] https://en.wikipedia.org/wiki/Coherence_length

[6] https://en.wikipedia.org/wiki/Jones_calculus

[7] MICOS GmbH, *User Manual Laser Education Kit CA-1300/1301 Michelson Interferometer* (Version 1/09 (2009).

[8] https://en.wikipedia.org/wiki/Michelson_interferometer

[9] Parameswaran Hariharan, *Basics of interferometry* (Elsevier Academic Press, Amsterdam, 2007).

Further reading

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Francis Graham-Smith, Terry A. King, Dan Wilkins, *Optics and photonics: an introduction* (Wiley, Chichester, 2008).