Determining the wavelength of the light of an He-Ne laser using a Michelson interferometer

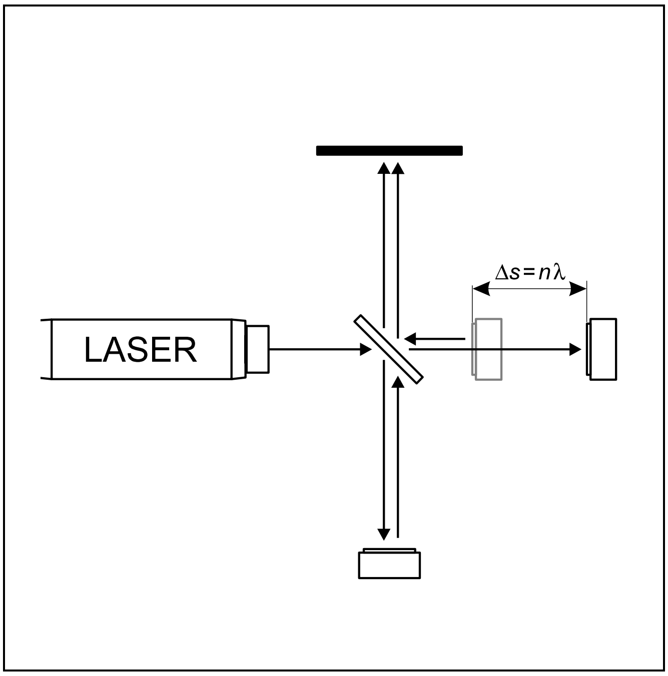
Objects of the experiment

- Assembling a Michelson interferometer
- To observe the interference pattern

Principles

Interferometry is an extremely precise and sensitive measuring method for determining e.g. changes in lengths, layer densities, refractive indices and wavelengths. The Michelson interferometer belongs to the family of two-beam interferometers. It operates on the following principle:

The coherent light beam supplied by a suitable source is split into two parts by an optical component. These partial beams travel along different paths, are reflected into each other and channeled to another optical component, where they are combined and superimposed. The result is an interference pattern. If the path length of one of these partial beams, i.e. the product of the refractive index and geometric path, changes, this produces a phase shift with respect to the undisturbed beam.



This in turn causes a change in the interference pattern, which allows us to draw conclusions about the changes in either the refractive index or the optical path when the respective other quantity remains constant.

This means that, when the refractive index remains constant, we can determine differences in the geometric path, e.g. changes in the dimensions of materials due to heat or the effects of electric or magnetic fields. On the other hand, if the geometric path remains constant, we can determine refractive indices as well as quantities and influences which affect the refractive index, such as changes in pressure, temperature or density.

In order to measure the wavelength of laser light, one of the planar mirrors is shifted by a precisely measurable distance using the fine adjustment mechanism; this change alters the optical path length of the respective partial beam. During this shift, the interference lines move across the translucent observation screen. To evaluate this phenomenon, we can count either the maxima or the minima which pass a fixed point on the observation screen while the planar mirror is being displaced.

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Apparatus

1 laser optics base plate		473 40
1 He-Ne laser, linearly polarized		471 840
1 laser support		473 41
5 optics bases		473 42
1 beam divider	e. g.	473 432
1 holder for beam divider		473 43
2 planar mirrors with fine adjustment		473 46
1 spherical lens, f = 2.7 mm		473 47
1 fine adjustment mechanism		473 48
1 translucent screen		441 53
1 saddle base		300 11
1 wooden ruler		311 03

Safety note

The He-Ne laser fulfills the German technical standard “Safety Requirements for Teaching and Training Equipment – Laser, DIN 58126, Part 6” for class 2 lasers. When the precautions described in the Instruction Sheet are observed, experimenting with the He-Ne laser is not dangerous.

- Never look directly into the direct or reflected laser beam.
- Do not exceed the glare limit (i.e. no observer should feel dazzled).

Setup

Note: optical components with damaged or dirty surfaces can cause disturbances in the interference pattern.
Handle the planar mirror, beam divider and spherical lens carefully, store them free of dust and to not touch them with your bare hands.

Fig. 1 shows the setup of the Michelson interferometer on the laser optics base plate. To set up the experiment correctly, you must carry out the following steps:

Laser optics base plate and laser:

- Pump up the air cushion.
- Place the laser optics base plate **(a)** with air cushion horizontally on a sturdy laboratory bench.
- Mount the laser on the laser support and place it at the left edge of the base plate.
- Connect the laser and switch it on.
- Loosen the three lock nuts of the adjusting screws on the laser support.
- Using the adjusting screws, adjust the height and inclination of the laser so that the beam travels perfectly horizontally about 75 mm above the base plate (there is still enough play for subsequent adjustment). Measure the spacing with the ruler.
- Tighten the lock nuts.

Beam divider:

The reflected and transmitted partial beams should have similar intensities.
When using the variable beam divider (473 435), make sure that the laser beam strikes the beam divider more or less in the center.

- First make sure that the beam divider **(b)** reflects the laser beam horizontally. To do this, place the beam divider with optics base in the beam path at the opposite end of the laser optics base plate and reflect the laser beam to a point next to the laser emission aperture.
- Correct the inclination of the beam divider, and thus the beam path, as necessary using the two adjusting screws on the rod.
- Finally, place the beam divider in the beam path at an angle of 45°, as shown in Fig. 1. The partially transparent layer of the beam divider should face the laser.

Planar mirrors and fine adjustment mechanism:

Notes:

It is easier to adjust the setup in a somewhat darkened room.

In addition to the main beams, the multiple reflections also produce so-called parasitic partial beams of low intensity. These are subsequently screened out by the lens holder and can thus be ignored in subsequent adjustment.

The quality of the laser beam is impaired when the partial beams reflected by the beam divider are reflected directly into the emission aperture of the laser.

- Mount planar mirror **(c)** laterally in the fine adjustment mechanism **(f)** and then mount the fine adjustment mechanism in an optics base.

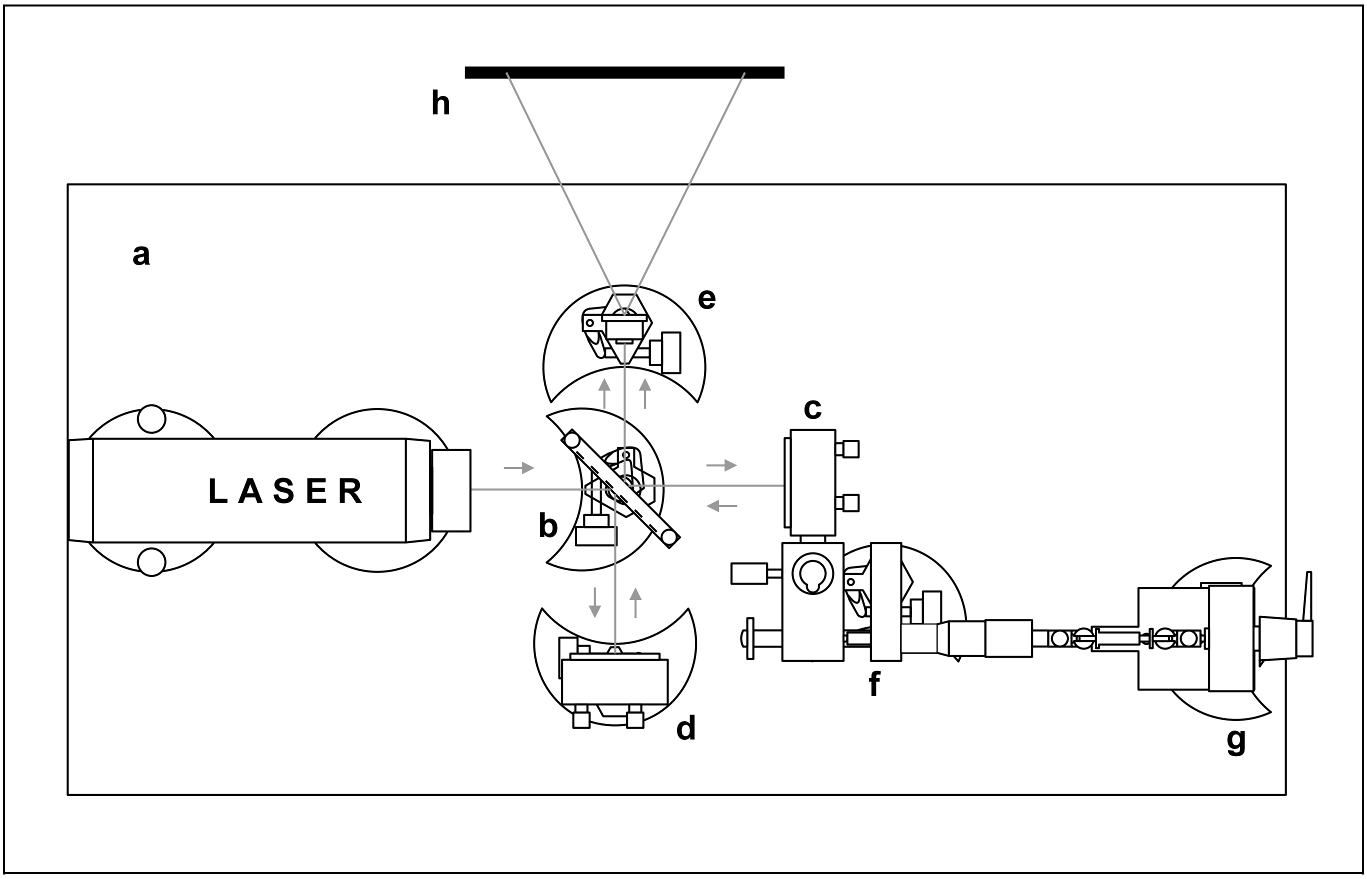

Fig. 1: Setup of the Michelson interferometer on the laser optics base plate with fine adjustment mechanism for one planar mirror, top view
a laser optics base plate
b beam divider
c,d planar mirrors with fine adjustment
e spherical lens
f fine adjustment mechanism
g reducing gear for fine adjustment mechanism
h translucent screen

- Align the optics base under the fine adjustment mechanism as shown in Fig. 1 so that the component stands steadily.
- Arrange the planar mirror **(c)** and fine adjustment mechanism **(f)** on the laser optics base plate **(a)** so that the laser beam strikes the planar mirror in the center. Make sure that the plane of the mirror is as perpendicular as possible to the displacement direction, so that the laser beam is always reflected to the same point when the mirror is displaced.
- By turning the optics base on the laser optics base plate and manipulating the adjusting screws on the back, align the planar mirror so that the beam is virtually reflected into itself and, after transmission through the beam divider, is incident at a point just above the emission aperture of the laser.
- Place the stand for gear unit with optics base directly behind the fine adjustment mechanism.
- Attach the reducing gear of the fine adjustment mechanism **(g)** to the stand for gear unit using the magnetic strip.
- Carefully clamp the double universal-joint coupling to the joint head of the micrometer screw of the fine adjustment mechanism **(f)**.
- Move the optics base of the reducing gear **(g)** and adjust the height of the stand for gear unit so that the coupling rod is neither fully extended nor completely collapsed, as otherwise the measurement can be falsified later by displacement of the fine adjustment mechanism.
- Keep the angles of the individual segments of the universal joint coupling as small as possible (not greater than 45°).
- Check the alignment of the planar mirror **(c)** and readjust as necessary.
- Fasten the translucent screen **(h)** in the base and set it up behind the laser optics base plate as shown in Fig. 1 so that the laser beam strikes it in the center.
- Place planar mirror **(d)** in the partial beam reflected from the beam divider **(b)** as shown in Fig. 1; position it about as far away from the beam divider as planar mirror **(c)**.
- By turning the optics base on the laser optics base plate and adjusting the screws, align the planar mirror so that this partial beam is also virtually reflected into itself and is recombined with the first partial beam after transmission through the beam divider.
- Adjust the planar mirrors **(c)** and **(d)** using the adjusting screws so that the most intensive beams of the two reflection groups are completely coincident on the screen.

Spherical lens:

- Place the spherical lens **(e)** on the laser optics base plate between the beam divider and the translucent screen to widen the beam (the small opening of the lens holder must face toward the beam divider).
- Adjust the height and lateral position of the spherical lens so that the two partial beams pass through it axially.

Fine adjustment:

If you do not yet see a pattern of lines on the translucent screen:

– Change the beam path by slightly changing the alignment of the beam divider or the planar mirrors; readjust the spherical lens as necessary.

The more the partial beams run in parallel between the beam divider and the screen, the wider and farther apart the interference lines are.

– Adjust the interference pattern so that it is easy to observe by slightly changing the alignment of the beam divider or the planar mirrors.

If you cannot achieve a satisfactory image by fine adjustment, repeat the interferometer adjustment procedure from the beginning.

The interference pattern is much brighter and easier to observe when the laser is switched to an output power of 1 mW. As this can change the beam path slightly, you may need to adjust the beam path or the position of the spherical lens.

Carrying out the experiment

During the experiment:

– Avoid mechanical shocks to the laser optics base plate (e.g. do not shake or bump the table).
– Avoid air streaking in the setup, e.g. through breathing or drafts.
– Mark the position of an intensity maximum on the translucent screen **(h)** at which the passing interference lines can be counted.
– Turn the reducing gear slowly and evenly by lightly placing your finger on the crank of the reducing gear **(g)** until the interference lines start to move (you may require several revolutions).
– Then turn the reducing gear at least one more full turn.
– Keep turning the reducing gear and, at the same time, count the interference lines passing the mark and the number of rotations of the reducing gear.

Note: if the movement of the planar mirror, and thus the interference pattern, is "jerky", lubricate the slide bush of the fine adjustment mechanism.

Measurement example

Table 1: Number of counted intensity maxima Z as a function of the number of revolutions N of the reducing gear.

N	Z
1	16 ± 1
2	32 ± 1

Evaluation and result

The number of revolutions N of the reducing gear, the total displacement Δs of the planar mirror, the wavelength λ of the laser light and the number of intensity maxima counted Z have the following relation to one another:

$$Z \cdot \lambda = 2\,\Delta s \quad \text{with} \quad \Delta s = 5\ \mu\text{m} \cdot N \qquad \text{(I)}$$

The factor 2 occurs in this equation because the geometric path changes by Δs both for the arriving beam and the reflected beam.

Thus, we can determine λ using the equation:

$$\lambda = 2 \cdot \frac{\Delta s}{Z} \qquad \text{(II)}$$

Table 2: Displacement Δs of the planar mirror and the result for wavelength λ

$\frac{\Delta s}{\mu\text{m}}$	$\frac{\lambda}{\text{nm}}$
5	625 ± 39
10	625 ± 20

Table 2 contains the result for the wavelength λ. Within the limits of error, it agrees with the literature value of λ = 632.8 nm for the red He-Ne laser light. The measuring accuracy for λ is better, the greater the total displacement Δs is.