Measuring Wavelength, Polarisation and Beam Profile

Experiment Objectives

- Determining the wavelength of the beam emitted by a He-Ne laser
- Determining the direction of polarisation and degree of polarization of the emitted beam
- Measuring the beam profile of the emitted beam

Principles

The helium-neon laser is among the most common lasers. In experiment P5.8.1.1, a helium-neon laser is assembled using individual components. In experiment P5.8.1.2, the emitted laser beam's wavelength, degree of polarization, and beam profile are studied.

Wavelength

The wavelength of the emitted beam is determined by the difference in energy levels between two states of an atom responsible for the emission. The best-known example is the transition in Neon between one of the 5s states and one of the 3p states, which results in a wavelength of 632.8 nm (1.96 eV). Other transitions exist at 3.39 µm and 1.15 µm. The relevant wavelength is selected by the coating of the resonator mirror. These are highly reflecting only for the desired wavelength. Reflectivity is low for all the other wavelengths and therefore a laser process is not possible.

The wavelength is determined by diffraction on a grating. For a given grating constant g, the position of the n^{th} main maximum is obtained from:

$$n\lambda = g \sin\alpha. \qquad (1)$$

The angle α is obtained in the experiment as follows

$$\tan\alpha = \frac{d}{L} \qquad (2)$$

where 2d is the spacing between both main maximums and L is the distance from grating to screen.

Direction and degree of polarisation

Brewster windows are used in optical resonators to reduce losses in the resonator. The window area is tilted so as to form Brewster's angle with the optical axis. Therefore, light polarised parallel to the boundary surface is not affected by reflection. However, as usual, perpendicular polarised light is partially reflected. This causes the laser to favour one polarization direction over the other: the quality of the laser's resonator decreases when the laser is rotated in one polarisation direction and improves in the other. The laser oscillates in this preferred mode.

Direction and degree of polarisation are determined using the Malus's theorem: If an analyser is placed in a linear polarised beam of light, the intensity of the light that passes through is given by

$$I = I_0 \cos^2 \varphi \qquad (3)$$

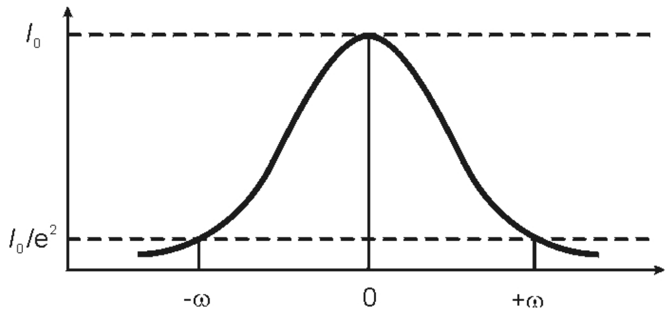
I_0; intensity of the incident light

φ: angle between the polarization direction and the analyser

Beam profile

Laser radiation consists of one or several radiation modes. Usually, the transverse intensity distribution is described in the so-called TE modes (TEM). These TE modes are distinguished by two indices that indicate how many zeros the electric field has in the x and y directions, z being the propagation direction of the radiation. So, a TEM_{mn} has m zeros in direction x and n zeros in direction y.

Fig. 1: Intensity distribution of a Gaussian shaped beam



Most gas lasers and many low-power solid-state lasers (e.g. He-Ne and ion lasers) emit in the fundamental mode, TEM_{00}. TEM_{00} has no zeros in the transverse direction. The intensity distribution is described by a Gaussian distribution (Gaussian shaped beam):

$$I(r) = I_0 \cdot e^{-\frac{2r^2}{\omega^2}} \qquad (4)$$

Here, I_0 is the maximum intensity and r is the distance to the optical axis. The distance from the optical axis is defined as the beam radius ω (beam diameter: 2ω), at which the intensity has dropped to I_0/e^2.

The TEM_{00} is diffraction-limited; this means that the product of the beam divergence and minimal beam radius along the propagation direction is constant (see Equation 4) and - in comparison to any other mode – takes the minimal possible value. That's why lasers are constructed so as to emit a beam in TEM_{00} if possible.

The beam profile is determined by expanding the beam through a lens at first. A photoelement is gradually moved perpendicular to the beam; a slit diaphragm is placed in front of it. The beam profile is determined from the current measured at the photoelement.

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Apparatus

1 Basic Set "He-Ne Laser" 471 810
1 Optical bench, 2 m, standard cross section 460 33
1 Holder with spring clips 460 22
1 Ruled grating 6000/cm (Rowland)...................... 471 23
1 Wooden ruler, 1 m long...................................... 311 03
1 Polarization filter... 472401
1 Lens in holder, f = 50 mm.................................. 460 02
1 STE Photoelement BPY 47................................ 578 62
1 Holder for plug-in elements 460 21
2 Connection lead, Ø 1 mm², 100 cm, black 500 444
1 Multimeter LDanalog 20 .... 531 120
1 Sliding rider 90/50 .... 460 383
1 Screen.. 441 531

Additionally recommended:
Adjustment goggles for He-Ne laser 471 828

Safety Notes

Warning: Make sure you also follow the instructions provided with the equipment!

The installed He-Ne laser complies with the Class 3B regulations according to DIN 60825-1 "Safety of Laser Products". Lasers belonging to Class 3B are potentially dangerous if a direct or mirror-reflected beam reaches the unprotected eye (directly looking at the beam).

- Do not look at the direct or reflected laser beam!
- Avoid unintentional mirror-reflections (e.g. through watches, jewellery, tools with metallic surfaces)!
- Block all laser beams by placing an absorbing or diffuse scattering material at the end of the purpose-related beam path.
- Wear laser adjustment goggles (471 828) if necessary.

Laser tubes require voltages >12 kV to ignite the gas discharge and contact-hazardous voltages of up to 2.5 kV for operation.

- The connection to the supply device should only be established through the high voltage plugs.
- Wiring and changes in the experiment setup should only be carried out when the supply device is switched off.
- The supply device should only be switched on when the circuit is completed.

The laser diode complies with the Class 2 regulations according to DIN 60825-1 "Safety of Laser Products". If you follow the corresponding hints in the instruction sheets, experimenting with the laser diode is harmless.

- Do not look at the direct or reflected laser beam.
- Avoid crossing the threshold line of glare (i.e. none of the observers should feel dazzled).

Preliminary remarks

The experiment only succeeds when the setup is thoroughly adjusted and all optical surfaces are free of impurities. Cleaning a precision optics system always represents a risk for the surface. In order to reduce the need to clean the optics as much as possible, they should be preserved in their original packing or they should be covered with a protective cover and placed in their support when they are not in use.

During the experiment, take measures to avoid the damage of mirror surfaces (including the rear side of the output mirror) and the Brewster window of the laser tube. Do not touch them with your bare hands. Immediately remove fingerprints, oil or water stains, because the skin acids attack the coating on the glass and permanent stains can be left behind.

If cleaning is necessary, it is advisable to use one of the methods recommended in the instruction sheets.

Setup and Method

Setup and calibration of the He-Ne laser are described in experiment P5.8.1.1. In this experiment, L = 60 cm is used as the mirror spacing. The laser tube is placed in the middle of the resonator.

Determining the wavelength

Setup is shown in Figure 3. The left edge position of the optics rider is given, in cm, for each element respectively.

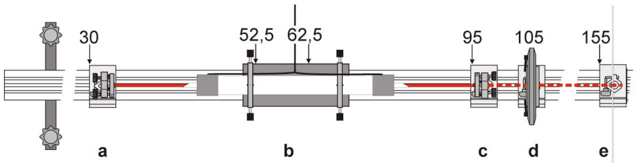

Fig. 2: Setup for determining the wavelength

- **a** Highly reflecting plane mirror HR
- b Laser tube in laser support
- c Output mirror OC, R = -1000 mm
- d Rowland grating in holder with spring clips
- e Screen

- Mount the Rowland grating in the holder with spring clips, behind the output mirror.
- Place the screen 50 cm away from the Rowland grating.
- With the help of the wooden ruler, determine the spacing between the first two main maximums.

Determining the direction and degree of polarisation

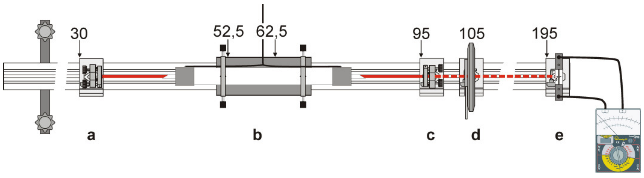

Fig. 3: Setup for determining the wavelength

- **a** Highly reflecting plane mirror HR
- b Laser tube in laser support
- c Output mirror OC, R = -1000 mm
- d Polarization filter
- e Photoelement on holder for plug-in elements

- Mount the polarization filter behind the output mirror.
- Mount the photoelement (**h**) on the holder for plug-in elements.
- Remove the screen and mount the holder for plug-in elements in the optics rider, so that the laser beam impacts the photosensitive side approx. at the centre.
- Using the current measurement cables, connect the photoelement to the multimeter. Switch on the multimeter.
- Change the orientation of the polarization filter in 5° increments, beginning at –90°. Read the respective currents on the multimeter and write them down in a table.

Determining the beam profile

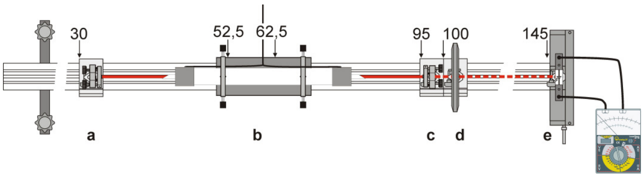

Fig. 4: Setup for determining the wavelength

- **a** Highly reflecting plane mirror HR
- b Laser tube in laser support
- c Output mirror OC, R = -1000 mm
- d Lens in holder, f = 50 mm
- e Photoelement on holder for plug-in elements

- Mount the lens (f = 50 mm) in the holder, directly behind the output mirror.
- Cover the photoelement with two dark paper strips, so that a little entrance slit, approx. 1 mm wide, is formed.
- Place the holder for plug-in elements and the photoelement in the sliding rider on the optical bench.
- First, align the sliding rider so that no laser light passes through the slit.
- Now, move the sliding rider gradually so as to shift the slit through the expanded laser beam. Read the respective positions and currents and write them down in a table.

Measuring example and analysis

Determining the wavelength

In the measuring example the spacing between the two main maximums, $2d$ = 41.3 cm, is obtained for a distance of L=50 cm from grating to screen. The grating constant of the grating used in this experiment is g = 1.67 µm. From equation (2) a deflection angle α = 22.4° is obtained. Using equation (1), we find λ = 637 nm is the laser wavelength. This corresponds to the literature value λ = 632.8 nm.

Determining the direction and degree of polarisation

A measuring example is shown in the following table.

φ / °	I/ mA	φ / °	I/ mA
-90	0.308	5	0.010
-85	0.298	10	0.020
-80	0.288	15	0.033
-75	0.268	20	0.051
-70	0.248	25	0.072
-65	0.228	30	0.094
-60	0.198	35	0.128
-55	0.168	40	0.148
-50	0.148	45	0.178
-45	0.118	50	0.198
-40	0.091	55	0.228
-35	0.070	60	0.248
-30	0.051	65	0.268
-25	0.033	70	0.288
-20	0.020	75	0.298
-15	0.009	80	0.298
-10	0.004	85	0.308
-5	0.001	90	0.298
0	0.004		

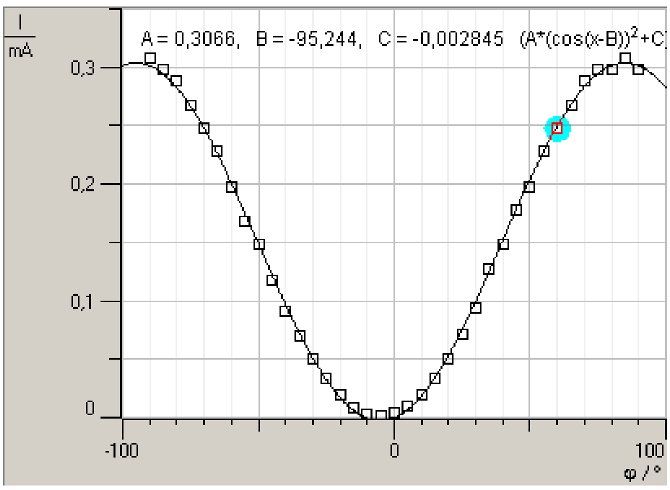

Fig. 5: Measuring the direction and degree of polarisation

Data is also plotted in Figure 5. The data corresponds well to a curve described by equation (3). The polarisation direction (parameter B) is –95°; this matches the Brewster window that faces the wall. The curve offset (parameter C) is very small; so the polarisation degree is nearly 100%.

Determining the beam profile

A measuring example is shown in the following table.

x / mm	I / µA
0.0	0.0
1.0	1.0
2.0	3.0
3.0	8.0
4.0	22.0
5.0	39.0
6.0	63.0
7.0	74.0
8.0	69.0
9.0	58.0
10.0	36.0
11.0	20.0
12.0	8.5
13.0	2.0
14.0	0.0
15.0	0.0

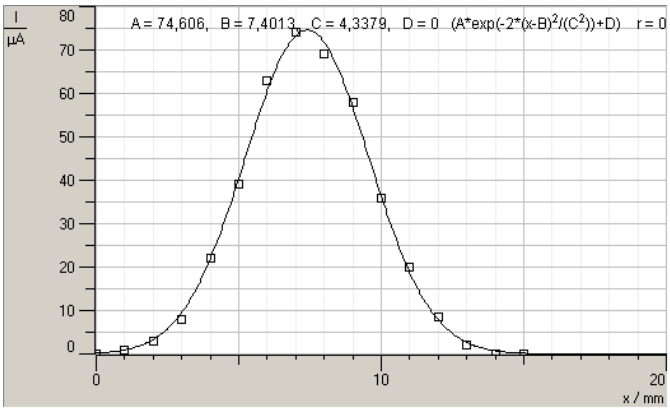

Fig. 6: Measuring the beam profile

Data is also plotted in Figure 6. The data corresponds well to a curve described by equation (4). The beam radius (parameter C), when measured at 50 cm from the lens, is ω = 4.33 mm.

According to the theorem on intersecting lines (see Figure 7) the beam radius ω_L can be determined at the lens location by using: $\frac{\omega_L}{\omega} = \frac{f}{L-f}$

If f = 50 mm and L = 500 mm, the results are:

$\frac{\omega_L}{\omega}$ = 0.11 or *ω_L = 0.48 mm.*

The beam diameter at the lens location and therefore at the approximate laser output is 0.96 mm.

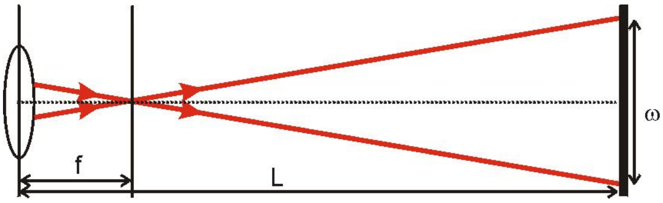

Fig. 7: Sketch for determining the beam radius at the lens location.