Optics

Laser Optics
He-Ne Laser

LD Physics Leaflets

P5.8.1.5

Stability Condition of an Optical Resonator

Experiment Objective

- Determining the output power for different spacing of the resonator mirrors
- Confirming the stability condition for optical resonators

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 P5.8.1.5, the stability condition for optical resonators is examined. Based on the resonator mirrors' mirror radiuses, you determine if a stable resonator setup is possible for various mirror distances.

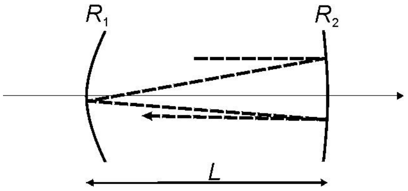

Fig. 1: Optical resonator

Figure 1 shows an optical resonator whose end-point mirrors have curvature radiuses R_1 and R_2 and distance L. An optical resonator is optically stable when a paraxial ray of light doesn't leave the mirrors, even after any number of reflections. In order to decide if a resonator is optically stable or not, the stability condition should be applied.

Optically stable: $0 \le g_1 g_2 \le 1$ (1)

Optically unstable: $g_1 g_2 < 0$ or $g_1 g_2 > 1$ (2)

with $g_1 = 1 - \frac{L}{R_1}$, $g_2 = 1 - \frac{L}{R_2}$

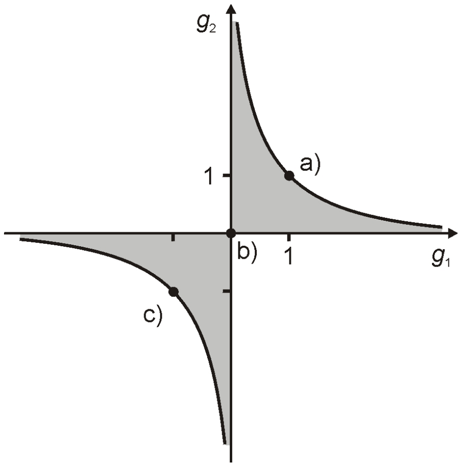

Fig. 2: Stability diagram of optical resonators

Figure 2 shows the stability diagram for optical resonators. Stable areas are marked in grey. The limits of the stability areas are determined by axes $g_1 = 0$, $g_2 = 0$ and the hyperbola $g_1 g_2 = 1$. In addition, three special cases are identified:

a) Planar resonator (Fabry-Perot resonator):
$R_1 = R_2 \rightarrow \infty \quad \Rightarrow \quad g_1 = g_2 = 1$

b) Confocal resonator:
$R_1 = R_2 = L \Rightarrow \quad g_1 = g_2 = 0$

c) Spherical (concentric) resonator:
$R_1 = R_2 = \frac{L}{2} \quad \Rightarrow \quad g_1 = g_2 = -1$

If two resonator mirrors with the same curvature radius R are used, then a stable setup for mirror spacing $0 \le L \le 2R$ is possible.

If a plane mirror is used, then one mirror radius is infinite: $R_1 \rightarrow \infty$. A stable resonator is obtained for mirror spacing $0 \le L \le R_2$.

In order to analyse the stability condition, the spacing between mirrors is gradually increased and the emitted power is measured for each distance. The measurement results are represented graphically and discussed with reference to the stability condition.

CS-0707

Apparatus

1 Basic Set "He-Ne Laser"	471 810
1 Optical bench, 2 m, standard cross section	460 33
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
Additionally recommended:	
1 Laser mirror, HR, R = -1000 m	470 103
Adjustment goggles for He-Ne laser	471 828

Safety Notes

Important: Make sure you 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.

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, make sure to avoid damaging any 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

Setup and calibration of the He-Ne laser are described in experiment P5.8.1.1. L = 50 cm is used as the initial mirror spacing. Figure 3 shows the setup for the present experiment. The left edge position of the optics riders is given, in cm, for each element respectively.

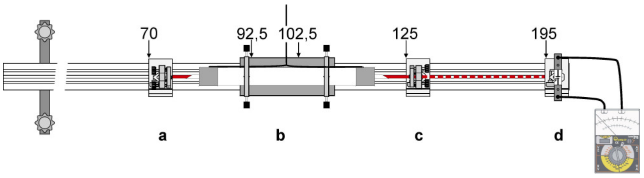

Fig. 3: Experiment setup

a	Highly reflecting plane mirror ($R_1 \rightarrow \infty$)
b	Laser tube in laser support
c	Output mirror OC, R_2 = 1000 mm
d	Photoelement on holder for plug-in elements

Method

Important: The laser process should not stop while moving the laser mirror. If necessary, shift the mirror in small increments and optimise the output power in each case, beginning with the shifted mirror. If the laser process stops, move the laser mirror back. If the laser process is not able to start again on its own, carefully turn the fine adjustment screw on the shifted mirror. If the laser process is still not starting, a complete recalibration is required (see Experiment P5.8.1.1).

When the setup has both a plane and a concave mirror, only the concave mirror is moved. This ensures that the amplifying medium volume matches the beam path as exactly as possible, for any spacing (see Experiment P5.8.1.4).

- Record position A of the highly reflecting mirror (**a**), position B of the output mirror (**c**) and the maximum current (see Table 1).
- Move the output mirror (**c**) 5 cm to the right, to create greater spacing between the mirrors, and optimise the output power beginning with the shifted mirror (**c**).
- Record position B of the output mirror (**c**) and the maximum current (see Table 1).
- Gradually move the output mirror (**c**) further away and record the maximum current for each distance, until laser activity is no longer visible.

If necessary, repeat the measurements for other noticeably different mirror separations or combinations of mirror radiuses. When the setup has two concave mirrors, both mirrors are moved symmetrically in relation to the laser tube. This ensures that the amplifying medium volume matches the beam path as exactly as possible (see Experiment P5.8.1.4).

Measuring example and analysis

Table 1 shows a measuring example for a plano-concave resonator with $R_1 \rightarrow \infty$ and $R_2 = 1000$ mm. Table 2 shows a biconcave setup with $R_1 = R_2 = 1000$ mm. The resulting mirror spacing L between position A of the highly reflecting mirror (**a**) and position B of the output mirror (**c**) is given by the equation: $L = B - (A + 5\ \text{cm})$. By adding 5 cm, we make sure that the location of the highly reflecting mirror is distinguished from the position reading.

A / cm	*B* / cm	*D* / cm	*I* / µA
70	125	50.0	520
70	130	55.0	480
70	135	60.0	500
70	140	65.0	500
70	145	70.0	520
70	150	75.0	530
70	155	80.0	500
70	160	85.0	490
70	165	90.0	460
70	167.5	92.5	440
70	170	95.0	400
70	172.5	97.5	200
70	175	100	27

Table 1: Measuring example for $R_1 \rightarrow \infty$ and $R_2 = 1000$ mm

A / cm	*B* / cm	*D* / cm	*I* / µA
70	125	50	700
65	130	60	660
60	135	70	730
55	140	80	620
50	145	90	530
45	150	100	440
40	155	110	660
35	160	120	740
30	165	130	730
25	170	140	720
20	175	150	710
15	180	160	700
10	185	170	770
5	190	180	810

Table 2: Measuring example for $R_1 = R_2 = 1000$ mm

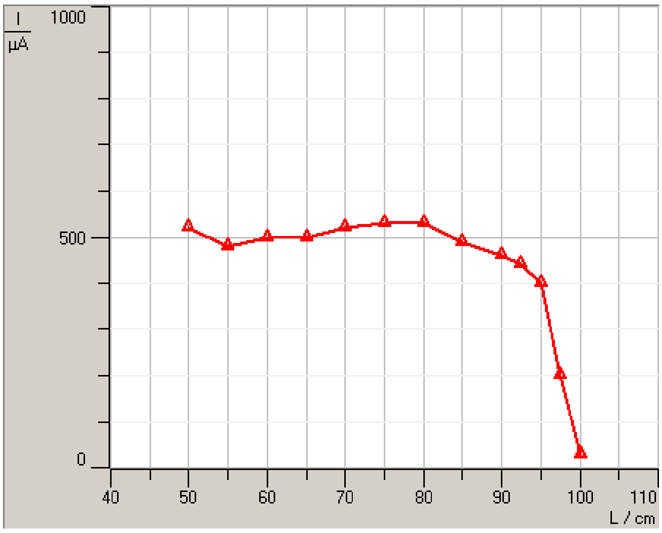

Fig. 4: Dependence of the output power on the mirror spacing for $R_1 \rightarrow \infty$ and $R_2 = 1000$ mm

In Figure 4, the measured values from Table 1 (plano-concave resonator) are represented graphically as a function of distance *D*. If the spacing between the laser mirrors is small, the resulting output power is high. Output power decreases as the space between mirrors increases. For $D > 100$ cm laser activity is no longer possible. This result agrees with the stability condition. A stability range of $R_1 \rightarrow \infty$ and $R_2 = 1000$ mm: $0 \le L \le 100$ cm can be determined using equation (1).

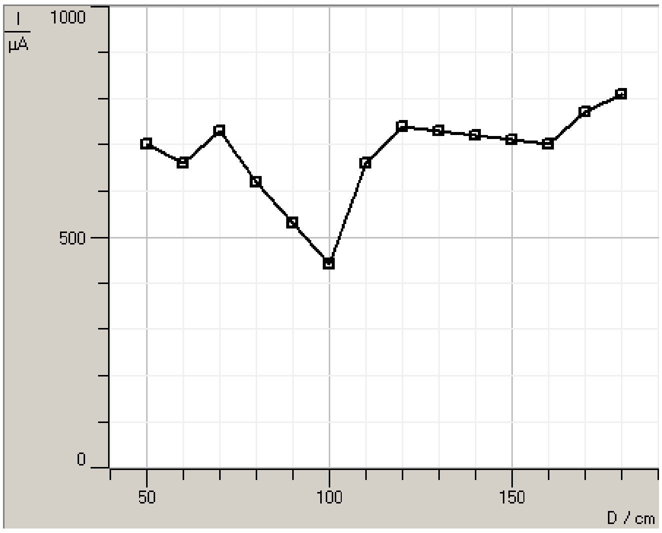

Fig. 5: Dependence of the output power on the mirror spacing for $R_1 = R_2 = 1000$ mm

Figure 5 shows measured values *I* from Table *2* (biconcave resonator). The current reaches its minimum at 100 cm, exactly corresponding to the confocal setup. A stability range of $R_1 = R_2 = 1000$ mm: $0 \le L \le 200$ cm is determined using equation (1).

The limits of the stability range can't be reached in this experiment. That's why laser activity is possible in the entire tested range.