University of Science and Technology of Hanoi

Department of Space and Application

Experiment Report

Photonics and Optics

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Contents

1 Michelson interferometer - high resolution **3**

1.1 Overview . . . 3
1.2 Setup and procedure . . . 4
1.3 Michelson interferometer on carrier plate . . . 6
1.4 Result . . . 8

2 Dispersion and resolving power of the prism and grating spectroscope **11**

2.1 Setup . . . 11
2.2 Procedure . . . 12
2.3 Result . . . 13

3 Fresnel's law - theory of reflection **17**

3.1 Principle and task . . . 17
3.2 Equipment . . . 17
3.3 Setup . . . 17
3.4 Result . . . 19

4 Fibre Optics **24**

4.1 Setup . . . 24
4.2 Procedure . . . 25
4.3 Results . . . 26

5 Sol'Ex grating spectrograph **29**

5.1 Principle . . . 29
5.2 Setup and Procedure . . . 29
5.3 Result . . . 30

List of Figures

1 Final set-up of high-resolution michelson . . . 4
2 Plate Carrier Michelson . . . 7
3 Relationship between the shift of mirror and wavelength . . . 9
4 The Michelson interferometer experiment . . . 10
5 Dispersion curve . . . 14
6 Yellow 1,2-Green Lines . . . 15
7 Blue Line . . . 15
8 Green-Turquoise Lines . . . 16
9 Green-Turquoise-Violet Lines . . . 16
10 Setting up The Fresnel's experiment . . . 19

11 Reflection coefficients correspond to angle of incidence for light polarized perpendicular and parallel to the plane of incidence 21
12 Reflection coefficients correspond to angle of incidence for light polarized perpendicular and parallel to the plane of incidence comparing the theory with experiment 23
13 Setup of fibre optics 24
14 Fibre optics relative power as the function of the angle readout with sine fit . . . 27
15 Fibre optics output power measurement 28
16 Output power from the fibre optics as the function of injection current 28
17 The Sol'EX 30
18 The spectrum on the screen from the test bench 31
19 The spectrum on the screen from the SpectrumMate, after slicing the images . . 32

List of Tables

1 Result of the Michelson interferometer experiment. d: the shift of mirror. n: number of fringed counted 8
2 Measurement results of prism 13
3 Measurement results of grating 14
4 Equipment List 18
5 Reflection coefficients correspond to angle of incidence for light polarized perpendicular and parallel to the plane of incidence 20
6 Reflection coefficients in theoretical calculation 22
7 Angle readout and Relative output power Data 27

1 Michelson interferometer - high resolution

1.1 Overview

Principle

With the aid of two mirrors in a Michelson arrangement, light is brought to interference. While moving one of the mirrors, the alteration in the interference pattern is observed and the wavelength of the laser light determined.

Equipment

Position No.	Material	Order No.	Quantity
1	Optical base plate 450×600 mm	$08750-00$	1
2	He-Ne Laser, 632 nm, 1 mW, linear polarised	$08182-93$	1
3	Surface mirror 30×30 mm	$08711-01$	4
4	Accesory set for optical base plate	$08750-50$	1
5	Holder for diaphragms and beam splitters	$08719-00$	1
6	Beam splitter 1/1, non polarizing	$08741-00$	1
7	Lens, mounted, $f+20$ mm	$08018-01$	1
8	Lensholder for optical base plate	$08723-00$	1
9	Screen, white, 150×150 mm	$09826-00$	1
10	linear translation stage, 25 mm	$08750-09$	1
11	Photoelement	$08734-00$	1
12	Digital multimeter 2005	$07129-00$	1
13	Measuring tape, I 2 m	$09936-00$	1
14	Adjusting support 35×35 mm	$08711-00$	4

*alternative to Photoelement and Digital multimeter: Digital array camera, Order No. 35612-99 with a connection to a PC/Laptop with at least Windows XP. Take caution during set up due to the size of the camera.

Task

1. Construction of a Michelson interferometer using separate components.
2. The interferometer is used to determine the wavelength of the laser light.
3. The contrast function K is qualitatively recorded in order to determine the coherence length with it.

1.2 Setup and procedure

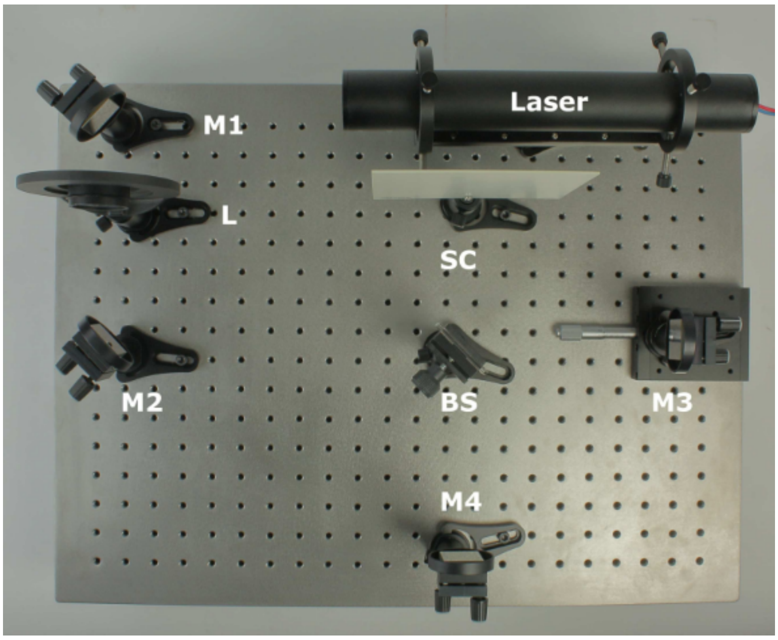


Figure 1: Final set-up of high-resolution michelson

The experimental set-up is shown in Figs. 1a and 1b, which serve as a rough guideline. The recommended set-up height (beam path height) is 120 mm. A ruler may be used to help measure the beam height and maintain such a height after placing each subsequent optical component on the base plate.

Note: Once the opitcal component is mounted on a foot and correctly positioned on the optical base plate, tightly clamp the foot to avoid unwanted movement.

Caution: Never look directly into a non attenuated laser beam.

- The lens L must not be in position when making the initial adjustments.
- When adjusting the beam path with the adjustable mirrors M1 and M2, the beam path is aligned straight along the base plate until it reaches M3 (done initially without the beam splitter BS). M3is mounted on the linear translation stage as seen in Figs. 1a and 1b. Adjust the mirror M3,
- again without the beam splitter BS, such that the reflected beam strikes the same point on mirror M2 from which it previously originated.
- Now, place the beam splitter BS with its metallized side facing mirror M2 in the beam path in such a manner that a partial beam strikes mirror M3 unchanged and the other partial beam strikes mirror M4 perpendicularly along the base plate.

- The beam which is reflected by mirror M4 must now be adjusted with the adjusting screws such that it strikes the same point on screen SC as the partial beam that originated at mirror M3 and was subsequently reflected by the beam splitter BS. A slight flickering of the luminous points which have been made to coincide indicates nearly exact adjustment.
- By placing the lens L in the beam path the luminous points are expanded.
- Now observe the interference patterns on screen SC (stripes, circles).
- By meticulously readjusting the mirrors M3 and M4 using the adjusting screws, one obtains concentric circles.

On determining the wavelength of the laser light:

- To perform this measurement, the path distance between the mirror M3 and the beam splitter BS must be changed. In the process, the position of mirror M3 is altered using a lever arm (lever transmission ratio approx. 20:1) and a micrometer screw (2 turns correspond to 1 mm), and thus the optical path length of the light beam is also changed.
- On changing the optical path lengths, one sees changes in the centre of the interference rings from maxima to minima and vise versa. Whether the path length increases or decreases becomes apparent in the following: for decreasing path length, the centre represents a source of maxima and minima; or for increasing path length it is a sink for the interference maxima and minima.
- According to the theory a change from minimum to minimum occurs when the optical path length ·d is changed by , i.e. in the set-up used the distance between the beam splitter BS and the mirror M3 changes by.
- To determine the wavelength of laser light, the changes in the distance between M3 and BS are measured (by reading the initial and final values on the micrometer screw) and the number of changes from minimum to minimum (or maximum to maximum) are counted.

On recording the contrast function:

- In this case, the screen SC is replaced by a photo cell PD for the determination of the contrast function K. To ensure that the photocell does not measure the intensity across different maxima and minima of the circular interference fringes, reduce the size of the slotted diaphragm with black tape such that only a small aperture of approximately 1 mm2 remains

  in the middle.
- For this part of the experiment, make the room as dark as possible to keep the dark current of the photocell as low as possible.

- To determine the contrast function, measure the intensities of minima and maxima by varying the optical separation of the mirrors. Change the separation using only mirror M4. This mirror is only to be moved along a straight path.
- Measure the distance between mirrors and beam splitter with a measuring tape. During the repositioning procedure, the mirror must be readjusted at each new position (if necessary, initially without the lens, see above) such that the interference fringes again become visible.
- To measure the intensities of minima and maxima, alter the position of the mirror M3 slightly using the micrometer screw so that one can see which minimal and maximal voltage values can be measured with the multimeter (measuring range approx. 500 mV).
- The difference in optical path length between the two mirrors and the beam splitter should be varied between 0 and 10 cm: i.e. when the distance from M3 to the beam splitter is approximately 13 cm, mirror M4 should be at its minimum distance of approximately 8 cm from the beam splitter BS and at its maximum separation of circa 13 cm from it.
- In the process, one must take into consideration that the larger the separation differences are, the smaller the radii of the circular interference fringes are. Consequently, at large separation differences the measurement of the maximum and minimum intensities is uncertain and, as a result of the relatively large diaphragm aperture, subject to large errors.

1.3 Michelson interferometer on carrier plate

Functions

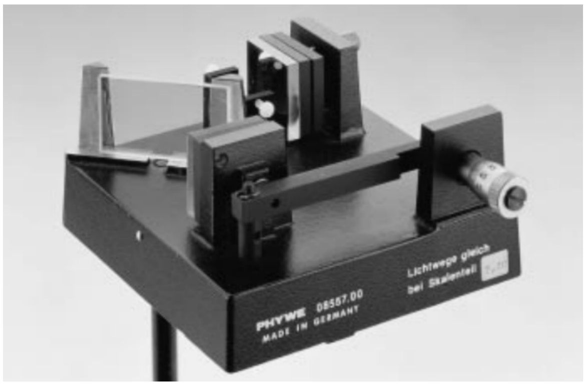
The Michelson arrangement on the carrier plate consists of two surface mirrors S1 and S2 which are posi- tioned at right angles to each other.

Mirror S1 is fixed, but can be tilted about two axes which are perpendicular to each other by means of adjusting screws on the back of it.

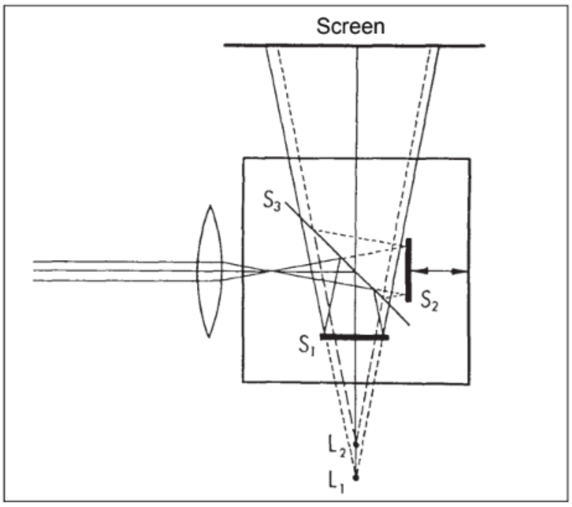
Mirror S2 can be moved in a direction perpendicular to its- elf by means of a micrometer screw and a 1:10 reduction lever. One graduation on the micrometer screw therefore corresponds to a mirror displacement of 1 μm.

The partially silvered mirror S3 is positioned at the intersection of the normals to the two mirrors. It serves to divide the incident beam into two equal beams.

A holder between S1 and S3 accepts a measuring cell for the examination of gases. The rods supplied can be fitted into the threaded bore in the underside of the carrier plate.



(a) Plate Carrier Michelson



(b) Schematic Diagram

Figure 2: Plate Carrier Michelson

Handling

Screw the longer rod into the interferometer (the shorter rod is for holding it in a magnetic base) to fix it in an optical bench at a distance of approximately 30 cm from the light source. When a laser is used as light source, as is most practical, then position a lens (f = 20 mm) halfway between the laser and the interferomenter to widen the laser beam.

Before doing this, however, adjust the arrangement without the widening lens. The laser beam should meet the partially silvered mirror at a 45° angle. Two patches of light are to be seen on a screen, perpendicular to the incident light. Use the adjusting screws to bring these patches to exactly coincide on top of each other (two further light reflections of less intensity, which result from reflection from the treated back of the mirror, have no effect on the measurement). Now place the lens for widening the light beam in position. As a rule a streaky interference pattern, resulting from a non-parallel alignment of the two mirrors, is now already to be seen. Carry out a sensitive readjustment with the adjusting screws to bring the interference pattern to the wanted concentric form.

The interferometer has an individual marking for the micrometer screw setting at which the paths of the divided beams are equal. Because of the different light paths 2d (Fig. 3: think here of one mirror turned in the direction of the other) the divided beams have the phase difference:

$$\delta = \frac{2\pi}{\lambda} 2dcos\theta$$

d (μm)	n	$\lambda = 2d/n$ (nm)
5	17	588.24
10	34	588.24
15	49	612.24
20	65	615.38
25	81	617.28
30	97	618.56
35	112	625.00
40	128	625.00
45	143	629.37

Table 1: Result of the Michelson interferometer experiment. d: the shift of mirror. n: number of fringed counted

As both divided beams have the same amplitude α, the intensity distribution is:

$$I \approx 4a^2cos^2\frac{\delta}{2}$$

Maximums therefore occur when δ is a multiple of 2π. We have then:

$$2dcos\theta = m\lambda \ ; \ m = 1, 2, ...$$

When the position of the mirror S2 is changed, so that e.g. d increases, the ring diameter will increase, as m is fixed for this ring. A ring therefore disappears each time d is increased by $\delta/2$.

To determine the wavelength of the light, it is best to start with an interference pattern with dark center, and then to displace mirror S2 by the path distance d so that n dark zones are passed through. The wavelength is then:

$$\lambda = \frac{2d}{n}$$

1.4 Result

We obtained the number of fringed corresponding to the value of the moving variation of the mirror.

The average wavelength we found:

$$\lambda_{avg} = 613.26 \pm 42.86 \text{ nm} \tag{1}$$

We know that the He-Ne Laser that we used has the standard wavelength of $\lambda_{stan} = 632$ nm. Therefore, the difference between the real wavelength the wavelength calculated from the

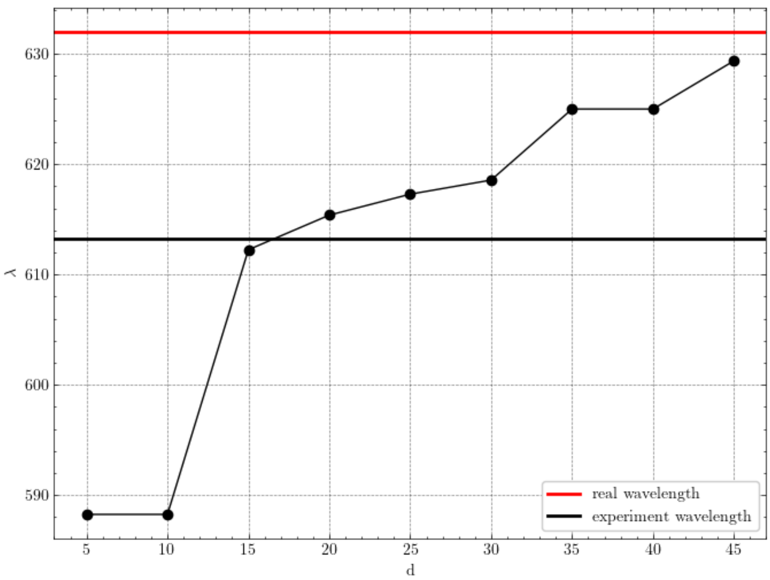


Figure 3: Relationship between the shift of mirror and wavelength

experiment is

$$\left|\frac{\lambda_{avg} - \lambda_{stan}}{\lambda_{stan}}\right| = 2.96 \pm 0.93\%$$

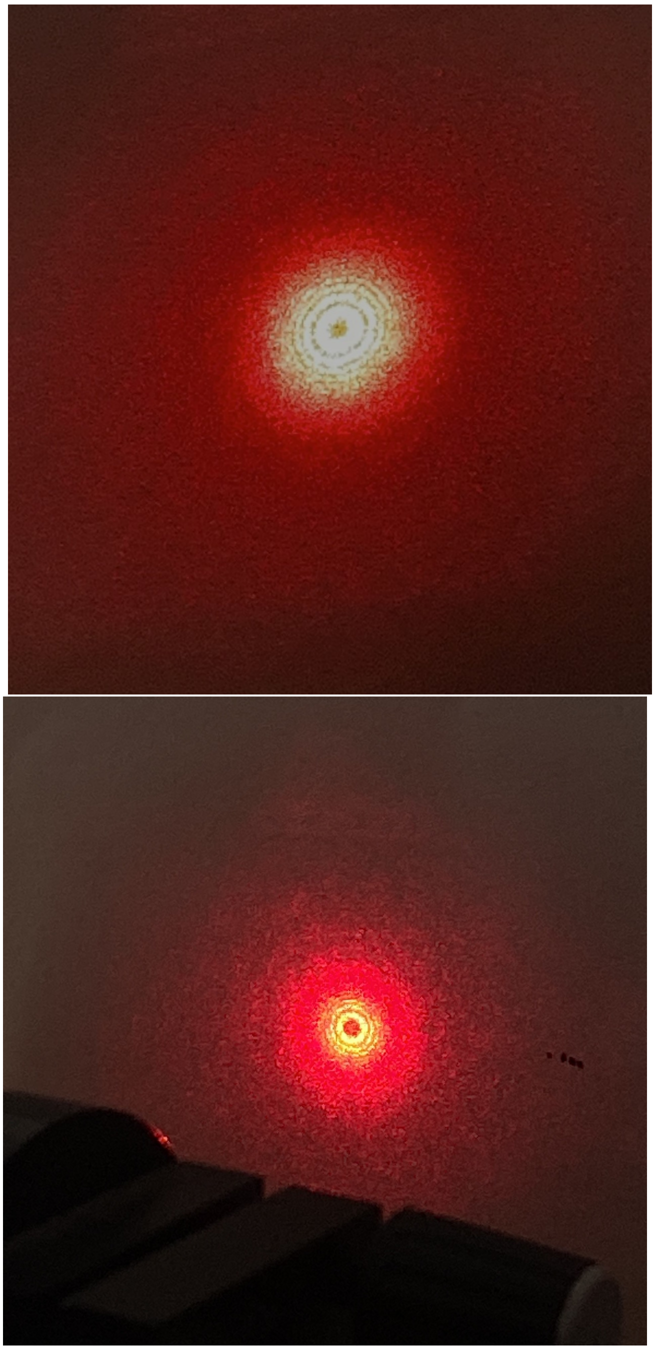


Figure 4: The Michelson interferometer experiment

2 Dispersion and resolving power of the prism and grating spectroscope

2.1 Setup

Experiment with the glass prism

The spectrometer-goniometer and the grating should be adjusted in accordance with the operating instructions. When the adjustment is correct, a parallel beam of light will pass through the prism. The aperture, or slit, is projected into the plane of the crosswires with the telescope set to infinity and observed with the eyepiece which is used as a magnifier. The prism is then set to the minimum deviation and the angular position 1 of the telescope is read off on the vernier for each spectral line. The prism is then turned so that the light falls on the adjacent surface and is deviated to the opposite side. The angle 2 is now read off for each spectral line, at minimum deviation. A ruled grating which is secured in a holder perpendicular to the collimator axis, and takes the place of the prism, is used to determine the wavelengths of the mercury spectral lines. The angles of first-order diffracted lines are measured to the right and left of the undeviated image of the slit.

The spectral lamp reaches its maximum lumiosity after approx. 5 minutes' warm-up time. When setting up the lamp, ensure that air can circulate unimpeded through the ventilation slots on the lamp housing.

Experiment with the grating

To start with, the telescope is adjusted to infinite distance. Then both tubes are adjusted horizontally with the adjusting screws and finally they are adjusted so that the directions of their axes coincide. The Hg-lamp is placed directly before the slit and must illuminate it completely. A sharp image of the slit is formed in the plane of the eyepiece scale and is observed using the eyepiece lens as a magnifying lens. The slit should be selected as narrow as possible. To start with, the grating constant of the high resolution Rowland grating is determined. For this, the grating is set perpendicular to the collimator axis and the grating table is fixed. The diffraction angles of the 6 high intensity Hg spectral lines are determined for the first and second order. Furthermore, recognizable third order lines should also be evaluated. The angle 2 of a spectral line of the same order of diffraction is measured to the right and to the left of the zero order. Two measurement readings are taken for every angle (two verniers).

Usually, the eyepiece scale is difficult to see, due to reduced brightness for higher orders diffraction. In these cases, better visibility may be obtained by lighting the grating askew from the direction of the telescope with a torch light. The number of illuminated grating slits is reduced to determine the resolving power of the grating. For this purpose, a slide caliper is placed as an auxiliary slit in front of the collimator lens in such a way, that no light reaches the grating when the caliper is closed.The auxiliary slit is then opened so that for example the yellow and green lines of Hg can be observed as clearly separate lines. The width x of the auxiliary slit is then reduced until the two lines merely appear separated. The average width of the auxiliary slit is determined over several experimental runs. Gratings with up to 50 lines/mm are used to determine the resolution required for the yellow-green lines. The Rowland grating is used to separate the pair of yellow Hg lines.

2.2 Procedure

Task 1:

To adjust the spectrometer-goniometer.

Task 2:

To determine the refractive index of various liquids in a hollow prism.

Task 3:

To determine the refractive index of various glass prism.

Task 4:

To determine the wavelengths of the mercury spectral lines.

Task 5:

To demonstrate the relationship between refractive index and wavelength (dispersion curve).

Task 6:

To calculate the resolving power of the glass prisms from the slope of the dispersion curves.

Task 7:

Determination of the grating constant of a Rowland gratin based on the diffraction angle (up to the third oder) of the high intensity spectral lines of mercury.

Task 8:

Determination of the angular dispersion of a grating.

Task 9:

Determination of the resolving power required to separate the different Hg-Lines. Comparison with theory.

2.3 Result

Prism

Reference angle: $260°40'30''$ and $80°50'$

The dispersion and resolving power of the prism:

$$n = \frac{sin(\dfrac{\theta+\delta}{2})}{sin(\dfrac{\theta}{2})}$$

No.	Color	λ (nm)	$\Phi(1)$	$\Phi(2)$	α	δ	θ	n
1	Violet	404.7	$208°47'$	$28°52'$	$51°53'30''$	$89°57'30''$	$13°49'30''$	6.54
2	Blue	435.4	$209°54'$	$29°44'$	$50°46'30''$	$90°5'$	$11°28'$	7.75
3	Turquoise	491.6	$211°2'$	$30°59'$	$49°38'30''$	$90°1'30''$	$9°15'30''$	9.44
4	Green	546.1	$211°58'$	$31°44'$	$48°42'30''$	$90°7'$	$7°18'$	11.8
5	Yellow	576.0	$212°19'$	$32°2'$	$48°21'30''$	$90°8'30''$	$6°15'30''$	13.7

Table 2: Measurement results of prism

The dispersion curve shows the relationship between the refractive index and wavelength:

Grating

The average angle of diffraction of the first and second order in opposite direction:

$$\Phi_{avg} = \frac{1}{4}(\Phi(1)_1 - \Phi(2)_{-1} + \Phi(2)_1 - \Phi(2)_{-1})$$

The grating constant can be expressed as:

$$g = \frac{z\lambda}{sin(\Phi)}$$

The average grating constant can be approximate as:

$$g_{avg} = 2.017 \pm 0.036\ \mu\text{m}$$

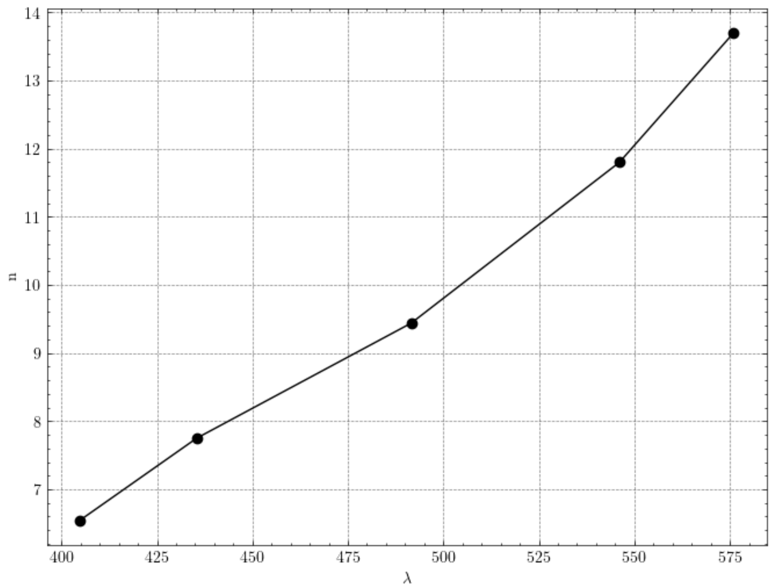


Figure 5: Dispersion curve

No.	Color	λ (**nm**)	$\Phi(1)_1$	$\Phi(2)_1$	$\Phi(1)_{-1}$	$\Phi(2)_{-1}$	$\boldsymbol{\Phi}_{avg}$	g (μm)
1	Violet	404.7	$272°33'$	$92°33'$	$249°19'$	$69°16'$	$11°38'$	2.007
2	Blue	435.4	$273°21'$	$93°18'$	$248°20'$	$68°17'$	$12°30'$	2.012
3	Turquoise	491.6	$275°00'$	$94°00'$	$246°42'$	$66°40'$	$13°54'$	2.046
4	Green	546.1	$276°22'$	$96°22'$	$245°9'30''$	$64°57'$	$15°39'$	2.024
5	Yellow 1	576	$277°30'$	$97°20'$	$244°14'$	$64°00'$	$16°39'$	2.01
6	Yellow 2	578	$277°40'$	$97°30'$	$244°8'$	$63°54'$	$16°47'$	2.001

Table 3: Measurement results of grating

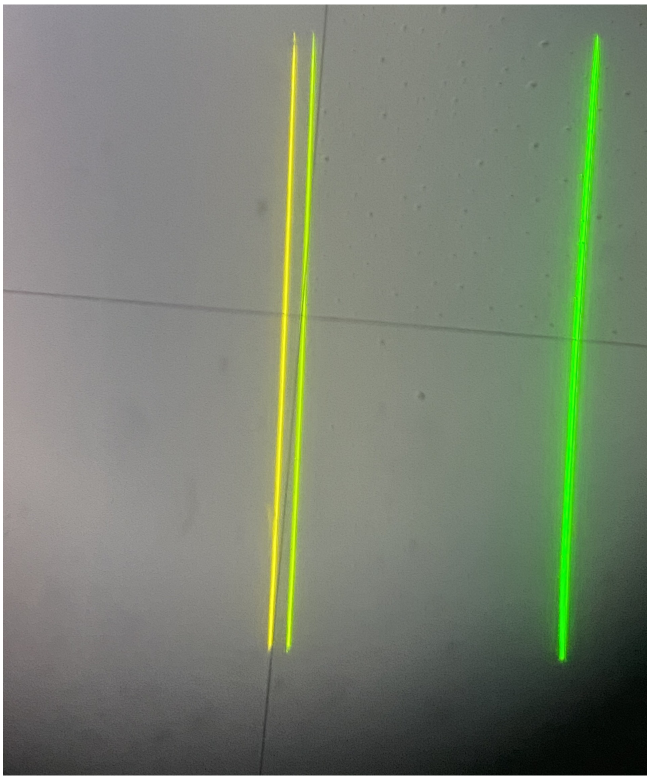


Figure 6: Yellow 1,2-Green Lines

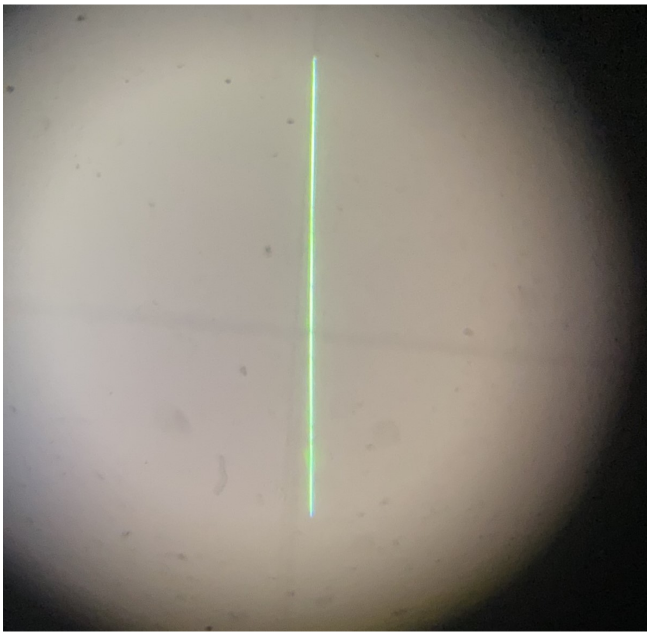


Figure 7: Blue Line

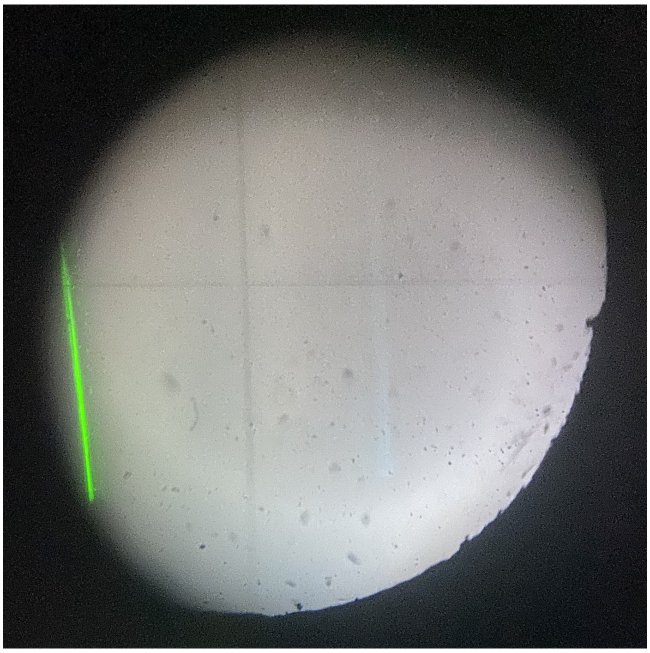


Figure 8: Green-Turquoise Lines

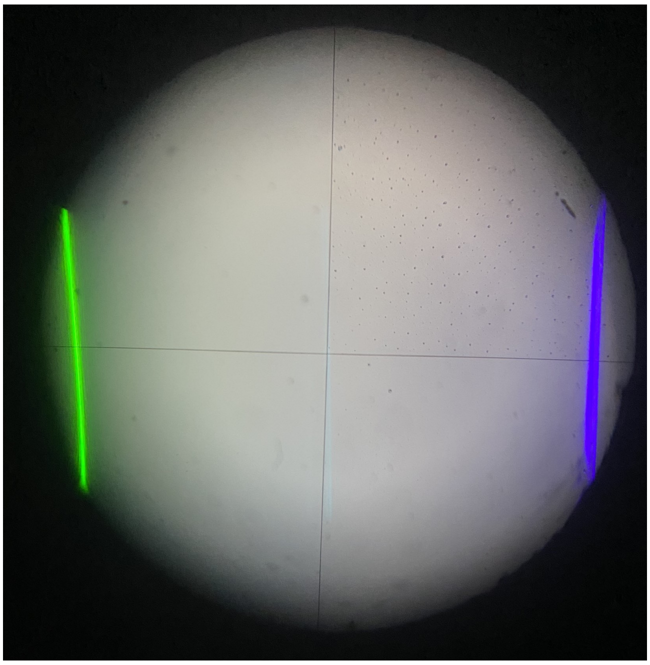


Figure 9: Green-Turquoise-Violet Lines

3 Fresnel's law - theory of reflection

3.1 Principle and task

Plane-polarized light is reflected at a glas surface. Both the rotation of the plane of polarization and the intensity of the reflected light are to be determined and compared with Frewsnel's formulae for reflection.

Task 1

The reflection coefficients for light polarized perpendicular and parallel to the plane of incidence are to be determined as a function of the angle of incidence and poltted graphically.

Task 2

The refractive index of the flint glass prism is to be found.

Task 3

The reflection coefficients are to be calculated using Fresnel's formulae and compared with the measured curves.

Task 4

The reflection factor for the flint glass prism is to be calculated.

3.2 Equipment

3.3 Setup

A. Setting up the swivel device

1. The pointer must first be screwed into the stand tube with its red tip pointing upwards. The stand tube is then insert- ed into the articulated radial holder until it reaches the stop and then tightened. The lower end of the stand tube is fastened in the tripod base.

2. The prism table, at which the protractor scale has been fixed, is fastened in the stand tube so that it can easily rotate but cannot wobble.

3. The support rods are fastened in the H-feet with the edge pointing upwards and joined to the articulated radial holder. The pointer and the longitudinal edge of the protractor scale should line up with the upper edge of the support rods. This can be easily carried out by turning the tripod base.

Equipment	Part Number	Quantity
Laser, He-Ne 1.0 mW, 220 V AC	08181.93	1
Polarising filter, on stem	08610.00	2
Prism, 60 degrees, h 36.4 mm, flint	08237.00	1
Prism table with holder	08254.00	1
Photoelement f. opt. base plt.	08734.00	1
Protractor scale with pointer	08218.00	1
Articulated radial holder	02053.01	1
Stand tube	02060.00	1
Tripod base -PASS-	02002.55	1
H-base -PASS-	02009.55	2
Right angle clamp -PASS-	02040.55	4
Support rod -PASS-, square, l 400 mm	02026.55	1
Support rod -PASS-, square, l 250 mm	02025.55	1
Support rod -PASS-, square, l 630 mm	02027.55	1
Multirange meter with amplifier	07034.00	1
Dry cell, 1.5 V	11620.34	6

Table 4: Equipment List

4. Finally, the clamping screw on the articulated radial holder is tightened slightly.

B. Beam path adjustment

1. The laser beam must be located over the centre of the prism table for finding the zero position.

2. Then the photocell, which is lined up with the support rod and switched to the maximum current range (300 mA), is swivelled into the beam. In this position the support rods are lined up with the longitudinal edge of the protractor scale.

3. The protractor scale is turned to zero to define the setting of the angle of incidence a = 0. Then the prism should be placed on the table with its reflecting surface centrally positioned so that the incident beam is reflected back along its own path.

C. Carrying out the measurements

1. After the laser has warmed up for about 15 minutes, the primary intensity $i_\circ$" of the beam polarized parallel to the plane of incidence is found. The laser is located in the normal position. Then the prism should be placed in position. After that, the angle of incidence is changed in steps of 5° from alpha $\leq$ 10° and a step angle of 1° should be selected in the region of the Brewster angle. The photocell is swivelled to obtain the maximum current for the determination of the intensity i_r".

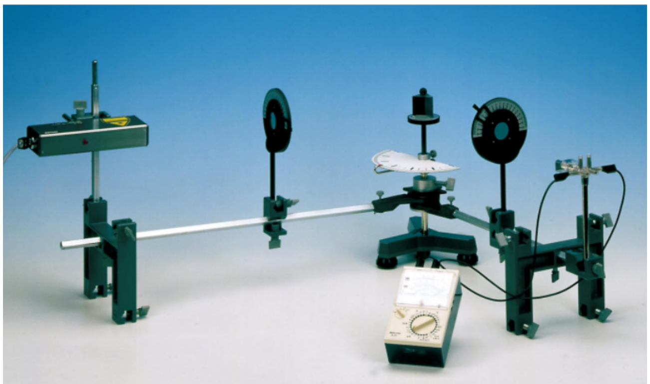


Figure 10: Setting up The Fresnel's experiment

Then the laser is turned through 90° and fixed on one of the legs on the H-base using the short support rod. The laser light is now oscillating normally polarized to the prism's plane of incidence. First, the primary intensity io must again be determined. Then the angle of incidence is varied in 5° steps and the corresponding intensity of the reflected beam is found.

2. The laser is set up again in the normal position for the determination of the degree of rotation of the polarization plane by reflection. The photocell is lined up to the direction of the beam without the prism in place. Using a polarization filter mounted in front of the laser for a precise determination of the plane of oscillation, the filter is turned until the registered intensity is at a minimum. Then the filter is turned through 45° and the prism placed in position using the familiar method. The degree of rotation of the plane of polarization for the reflected beam is found with a second polarization filter located between the prism and the detector. The angle of incidence is changed in 5° steps. The angle of rotation for the plane of polarization is the average of a number of measurements.

3.4 Result

The reflection coefficient measurement results corresponding to each incident angle value are shown in the table below. Use the following equations to calculate the reflection coefficient:

$$\zeta^{\parallel} = \frac{E_r^{\parallel}}{E_o^{\perp}}$$

and

$$\zeta^{\parallel} = \frac{E_r^{\perp}}{E_o^{\perp}}$$

If the reflected and refracted beam are perpendicular to one another ($\alpha + \beta = \pi/2$), we have

Table 5: Reflection coefficients correspond to angle of incidence for light polarized perpendicular and parallel to the plane of incidence

Angle	Parallel	$\zeta^{\parallel}$	Perpendicular	$\zeta^{\perp}$
0	3.4		3.2	
15	2.91	0.855	1.0	0.311
20	2.55	0.750	0.6	0.186
25	2.29	0.673	0.31	0.097
30	2.17	0.639	0.23	0.072
35	2.07	0.608	0.17	0.053
40	1.85	0.544	0.12	0.038
45	1.9	0.593	0.06	0.018
50	1.65	0.485	0.01	0.003
55	1.50	0.441	0	0
60	1.46	0.429	-0.01	-0.031
65	1.29	0.379	-0.02	-0.006
70	1.06	0.311	-0.02	-0.006
75	0.92	0.271	-0.02	-0.006
80	0.83	0.244	-0.01	-0.003
85	0.72	0.212	0	0
90	0.66	0.194	0.02	0.006
95	0.63	0.185	0.04	0.012
100	0.52	0.153	0.06	0.018
105	0.48	0.141	0.07	0.022
110	0.39	0.115	0.07	0.022
115	0.39	0.115	0.11	0.034

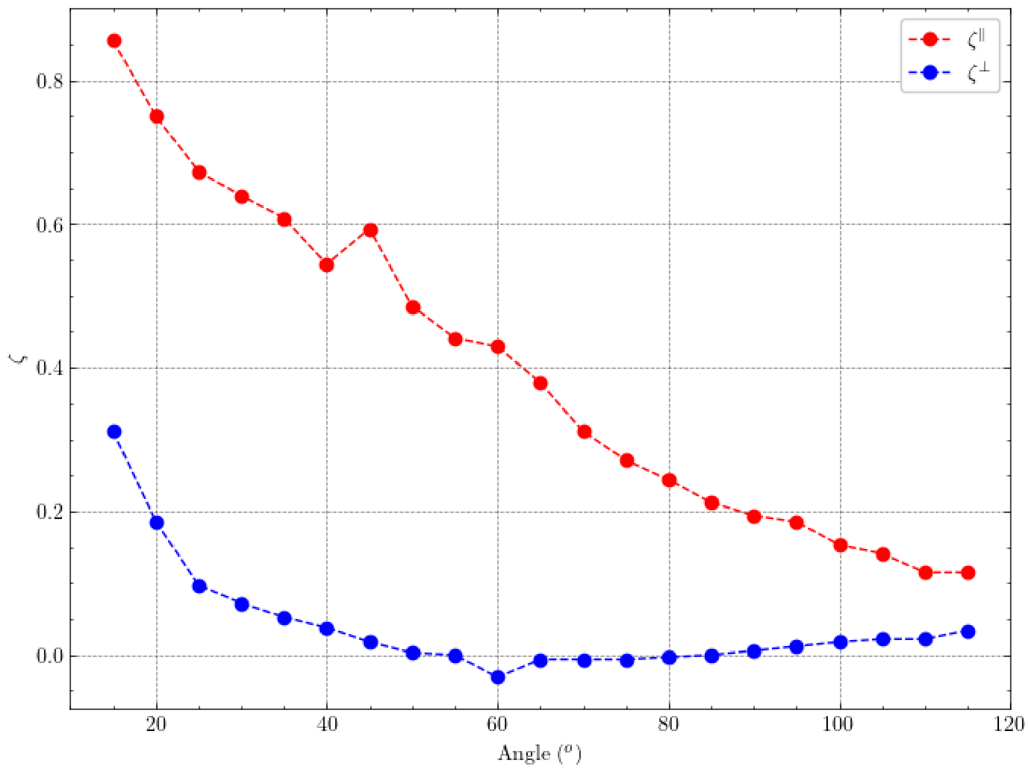


Figure 11: Reflection coefficients correspond to angle of incidence for light polarized perpendicular and parallel to the plane of incidence

$\zeta^{\perp} = 0$. Then, the reflected light beam is fully polarized. The electric vector oscillates in this case only normal to the plane of incidence. According to Snell's law of refraction:

$$sin(\alpha) = nsin(\beta) = nsin(\pi/2 - \alpha) = ncos(\alpha)$$

From Table 5, we chose angle $\alpha = 55°$with $\zeta^{\perp} = 0$ to and apply the above equation, we could find the index of the flint glass prism.

$$n = \frac{sin(55)}{cos(55)} = 1.428 \tag{2}$$

Using the Fresnel's equation with n = 1.428, we have the table like below.

$$\zeta^{\perp} = -\frac{(\sqrt{n^2 - sin^2(\alpha)} - cos(\alpha))^2}{n^2 - 1}; \zeta^{\parallel} = \frac{n^2 cos(\alpha) - \sqrt{n^2 - sin^2(\alpha)}}{n^2 cos(\alpha) + \sqrt{n^2 - sin^2(\alpha)}} \tag{3}$$

Table 6: Reflection coefficients in theoretical calculation

Angle	$\zeta^{\parallel}$	$\zeta^{\perp}$
15	-0.18	0.18
20	-0.24	0.22
25	-0.25	0.22
30	-0.26	0.20
35	-0.28	0.19
40	-0.30	0.17
45	-0.32	0.15
50	-0.34	0.12
55	-0.38	0.08
60	-0.42	0.04
65	-0.46	-0.02
70	-0.52	-0.10
75	-0.59	-0.19
80	-0.67	-0.31
85	-0.76	-0.48
90	-0.87	-0.70
95	-1.00	-1.00
100	-1.15	-1.44
105	-1.31	-2.09
110	-1.50	-3.18
115	-1.71	-5.22

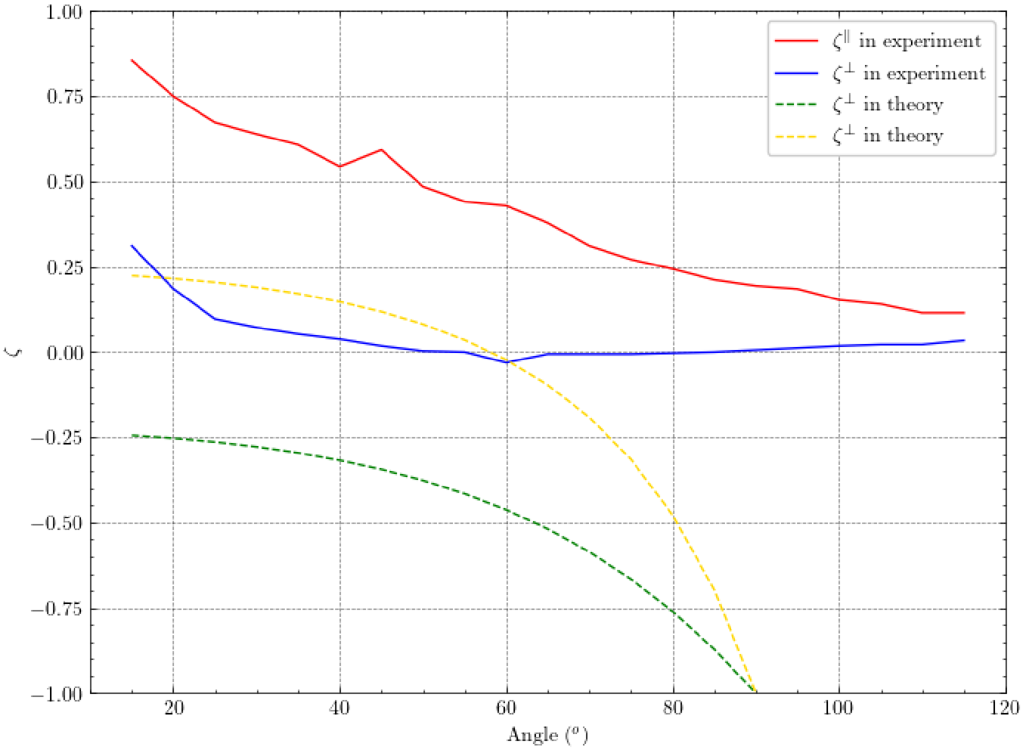


Figure 12: Reflection coefficients correspond to angle of incidence for light polarized perpendicular and parallel to the plane of incidence comparing the theory with experiment

We observe that the theoretical reflection coefficients decrease more rapidly with increasing angle of incidence compared to the experimental values. This discrepancy suggests that the experimental setup may introduce factors such as surface roughness, material properties, and environmental conditions, which are not fully accounted for in the theoretical model based on the Fresnel equations. Additionally, experimental limitations such as misalignment or calibration errors could also contribute to the observed differences. Overall, while the theoretical model provides valuable insights, discrepancies with experimental observations highlight the need for careful consideration of real-world factors when interpreting optical phenomena.

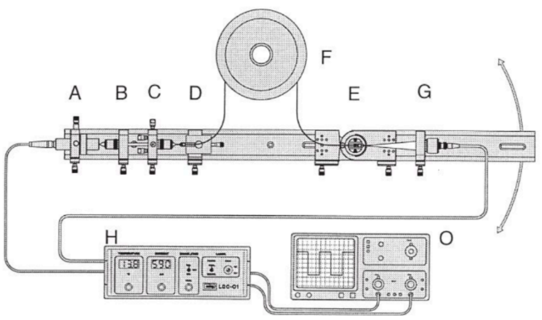
We calculate the reflection factor R:

$$R = (\frac{n-1}{n+1})^2 = (\frac{1.428-1}{1.428+1})^2 = 0.031 \tag{4}$$

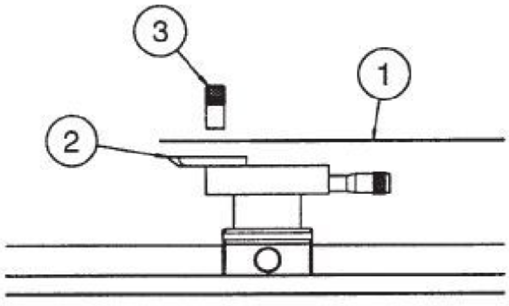
4 Fibre Optics

4.1 Setup

After eliminating the insulation from both fibre ends by scratching, the cut and cleaved fibre (1) is to put into the groove of holder (2) and carefully fixed with the magnet (3).



(a) Experimental set-up with monomode fibre



(b) Mounting the plug connection to module D

Figure 13: Setup of fibre optics

Module A: The laser diode in its housing is mounted on a XYfine adjustment. A Peltier cooler and a thermistor for measuring the laser diode temperature are incorporated in the housing. The laser diode emits a maximum power of 50 mW.

Module B: A microscope objective collimates the laser diode radiation. The objective is screwed into the mounting plate that it can easily be removed from the plate holder and exchanged for another one. Before we start with the measurements we have to define the optical axis of the set-up. This is done with the help of an oscilloscope. The injection current is modulated so that we can see rectangular pulses on the oscilloscope. The collimator (Module B) is brought at such a position to the laser diode that a nearly parallel laser beam is formed.

By means of the XY-displacement screws of Module A the laser beam is then centralised on the detector. This can be checked by looking for the maximum signal on the oscilloscope. Precaution has to be taken that the detector does not reach saturation. Eventually the injection current has to be reduced by a suitable amount. The next step is to bring the coupling optics (Module C) into the set-up.

Module C: Basically the same arrangement as Module B but with a fine adjustment holder with four axis XY, and and an objective of smaller focal distance to focus the collimated laser diode radiation in such a way that an effective coupling to the fibre is ensured. A beam shaping of the laser diode radiation has purposely been omitted to simplify the entrance into the experiment.

Module D: Before starting the experiment the prepared fibre is mounted to the Module D. The fibre holder is mounted on a stage with linear displacement in the direction of the beam.

Module F: 100 m monomode fibre are coiled up on a drum. Of course multimode fibres can also be used, which make alignment much easier.

Module E: On a hinged joined angle connector the second fibre holder is mounted, but without a linear stage. This device allows the measurement of the angle dependent output power of the fibre.

Module G: This module consists of the detector with a PIN photodiode. The connection to the preamplifier of the control unit LDC01 is made by a BNC cable. The inner pin of the BNC plug is in contact with the anode of the photodetector.

4.2 Procedure

Task 1:

For coupling the diodelaser beam into the fibre, the beam is first collimated by means of Module B. The distance of Module C to Module B is more or less arbitrary since the laser beam is nearly parallel. 50 mm are recommended. Now the fibre adjustment holder (Module D without fibre) is put on the rail at a distance of about 10 mm from Module C. The fibre is then carefully mounted to the fibre adjustment holder and inserted.

The laser diode is switched to maximum injection current and the internal modulation is “on”. The detector is fixed to the holder plate G in front of the fibre exit. If the amplifier of the control unit and the oscilloscope are set to highest amplification, one already detects modulated laser light at the exit of the fibre. Now the fibre has to be adjusted.

While observing the amplitude on the oscilloscope one turns gently the XY and (θ, Φ) adjustment screws of the adjustment holder. If there is no further increase in the amplitude the distance between fibre and coupling optics will be changed by acting on the linear displacement of the sliding mount.

In the new position the adjustment screws are readjusted. Since the amplitude increases continuously the amplification of the oscilloscope has to be reduced accordingly. At a certain state of adjustment the injection current has to be reduced since meanwhile so much power is coupled to the fibre that the detector approaches saturation.

By means of the IR conversion card one can now observe the outgoing radiation if the room is sufficiently darkened. The previous adjustment steps are repeated until no further power increase is observed. The set- up is now well prepared for the following measurements.

Task 2:

The control unit LDC01 has a modulation input to which a signal generator can be connected. That way the injection current can be modulated by any type of LF – signal. The signal generator should have an adjustable off-set to get the working point in the midst of the characteristic line of the laserdiode. Any source of signals can be used as a signal generator, also sources of digital signals, provided they have the required input voltage level.

Task 3:

The holder G with the PIN photodiode is positioned on the right rail at a distance not too far from holder E predetermined by the rotation joint. The output power of the fibre is measured for different angles from -10 to +10 degree. We use modulated light to eliminate the influence of environmental disturbances. The amplitudes are proportional to the light intensity.

Task 4:

The PIN photodiode is now placed at a distance of 2 cm in front of the diodelaser. The supply current of the diodelaser is modulated internally. After ensuring that the photodiode is not saturated the relative output power of the diodelaser is measured for increasing values of the supply current.

4.3 Results

After coupling the diodelaser beam into the fibre and injecting the maximum current, we measured the output power of the fibre from different angle from -10 to +10 degree. The result is shown in the table and figure below.

Table 7: Angle readout and Relative output power Data

Angle (°)	**Power (V)**
-10	0
-8	1
-6	14
-4	18
-2	19
0	20
2	20
4	17
6	13
8	5
10	0

As expected, the maximum power was recorded when the fibre lined up perfectly with the photodiode (0 degree). When the angle increase, the power output decrease in a sinusoidal behavior. The measure values in our experiment agree with the theoretical curve.

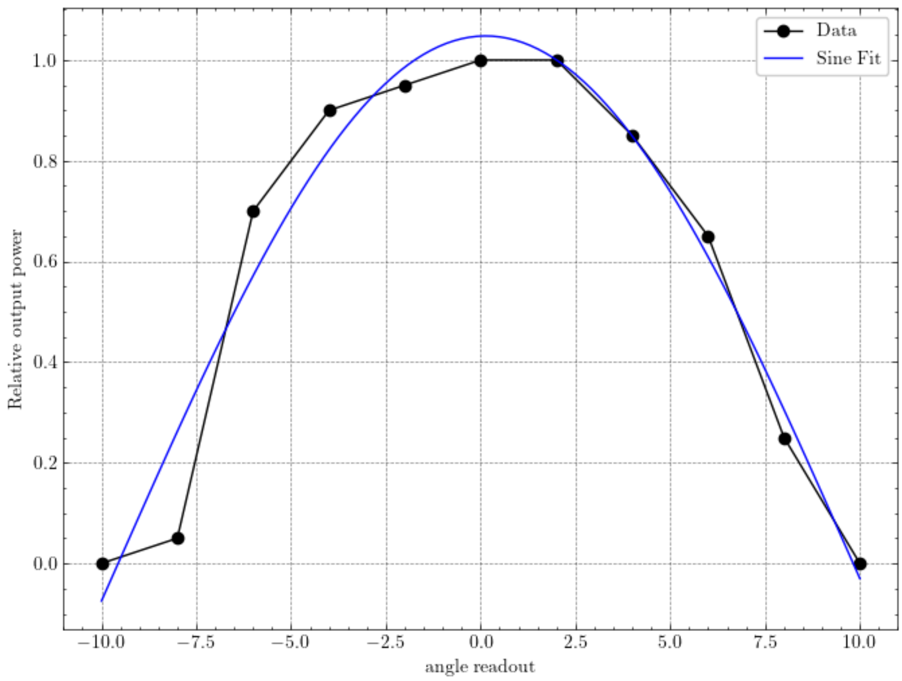


Figure 14: Fibre optics relative power as the function of the angle readout with sine fit

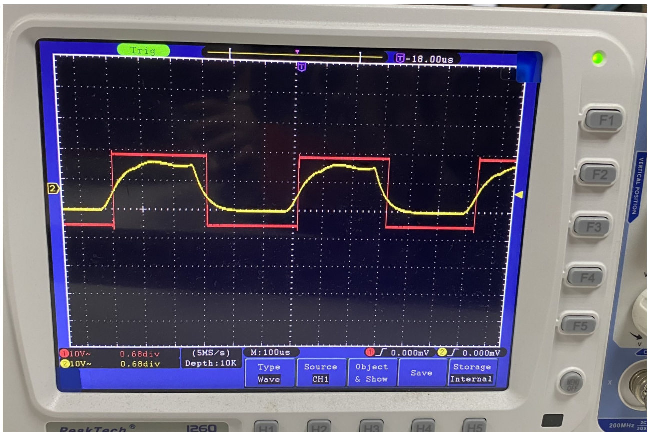


Figure 15: Fibre optics output power measurement

The output power of the fiber optics was measured as a function of current in milliamperes (mA). It was observed that there exists a threshold current below which no laser radiation output is observed. However, beyond this threshold current, the output power increases linearly with the supply current. This observation suggests the presence of a threshold current necessary to initiate laser radiation output, with the output power exhibiting a linear relationship with the supply current thereafter.

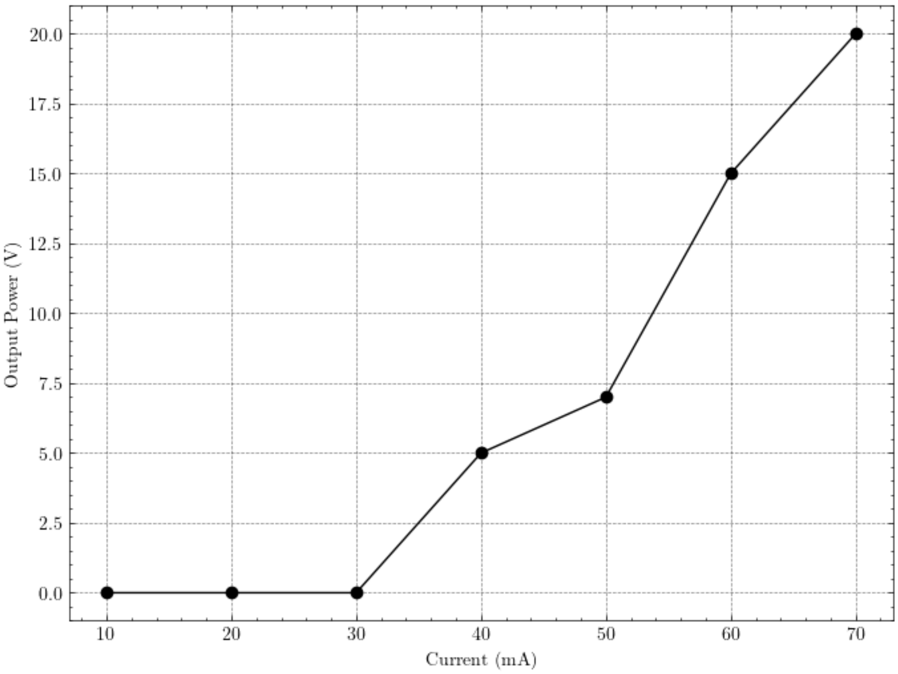


Figure 16: Output power from the fibre optics as the function of injection current

5 Sol'Ex grating spectrograph

5.1 Principle

A spectrometer is an essential tool for analyzing light properties across the electromagnetic spectrum, commonly employed in material identification through spectroscopic analysis. The SpectrumMate project comprises three main components: a collimator, a diffraction grating, and an objective tube. The collimator narrows and aligns a beam of light or radiation, ensuring its straight and parallel trajectory. The diffraction grating separates incident light into monochromatic components, while the objective tube focuses the diffracted light onto the camera's sensor using lenses.

5.2 Setup and Procedure

Requirements for SpectrumMate

SpectrumMate needed to have all the basic components of a spectrometer, which include a collimator tube, a grating, and an objective tube. To record spectrum images, a camera was also required. Since the optics used in SpaceLAB are different from those used in Sol'EX, the configuration and size of SpectrumMate's parts needed to be redesigned.

Product Quality

For product quality, SpectrumMate should be designed to prevent all light leakage, the parts should be tightly connected, and the optical components should fit perfectly. SpectrumMate should also be as compact as possible, since it is intended to be used with small telescopes.

Observation Requirements

In terms of observation requirements, the telescope needed to be collimated, aligned, and have good tracking ability. The spectrum images captured by SpectrumMate should be sharp enough for absorption and emission lines to be visible to the naked eye and processed by software.

Configuration of SpectrumMate

To find the suitable configuration, two setups were tested at SpaceLAB following the instructions in the EDU-SPEA1/M Economy Spectrometer Kit Manual and the EDU-SPEB2 Spectrometer Kit Manual (see **?**).

Experiment 1

There are five lenses used in the first setup. This configuration allows the maximum amount of light to be collected from the light source by using two condenser lenses. However, this

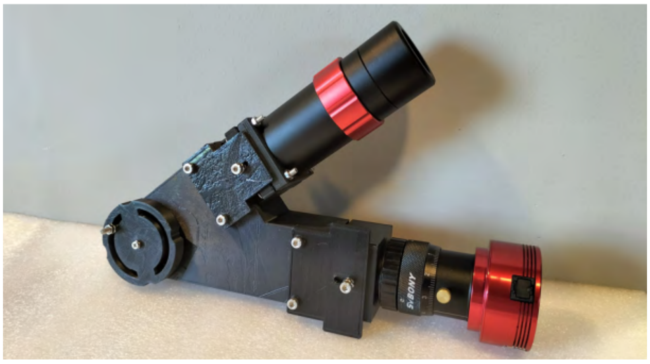


Figure 17: The Sol'EX

configuration was not chosen due to the complexity of aligning the optical components and the large amount of dispersion in the spectrum.

Experiment 2

In the second setup, there are only two lenses, which makes it easier to align the system. However, the spectrum is spreading too much, which makes it more difficult to achieve the compact design that was decided upon initially.

Consultation and Final Configuration

Since the two previous configurations had the same problem as the spectrum spreading widely, the configuration of Sol'EX was consulted. Sol'EX's configuration uses two doublets: one for collimating light from the slit, and the other for converging light onto the camera sensor. This configuration is simple, easy to build, compact yet effective since the spectrum is converged onto the camera sensor using an objective lens.

The final configuration of SpectrumMate was then decided. The design is the same as Sol'EX, the only difference is the lenses used in the system. With the use of two singlet lenses, chromatic aberration, which is a failure of a lens to focus all colors to the same point, caused an outline of color along the edge of absorption lines, which affects the result when using SpectrumMate. Though the effect was not pronounced strongly since the light is already dispersed by the grating.

5.3 Result

Experiment 1

In Experiment 1, we tried setting up using five lenses to capture as much light as possible. We thought having two lenses called condenser lenses would help with this. But it turned out to be quite tricky to put all these lenses in the right position. Plus, when we looked at the spectrum (the colors we see), it was spread out too much. This made our device bigger than we wanted it to be, which was a problem for using it with small telescopes.

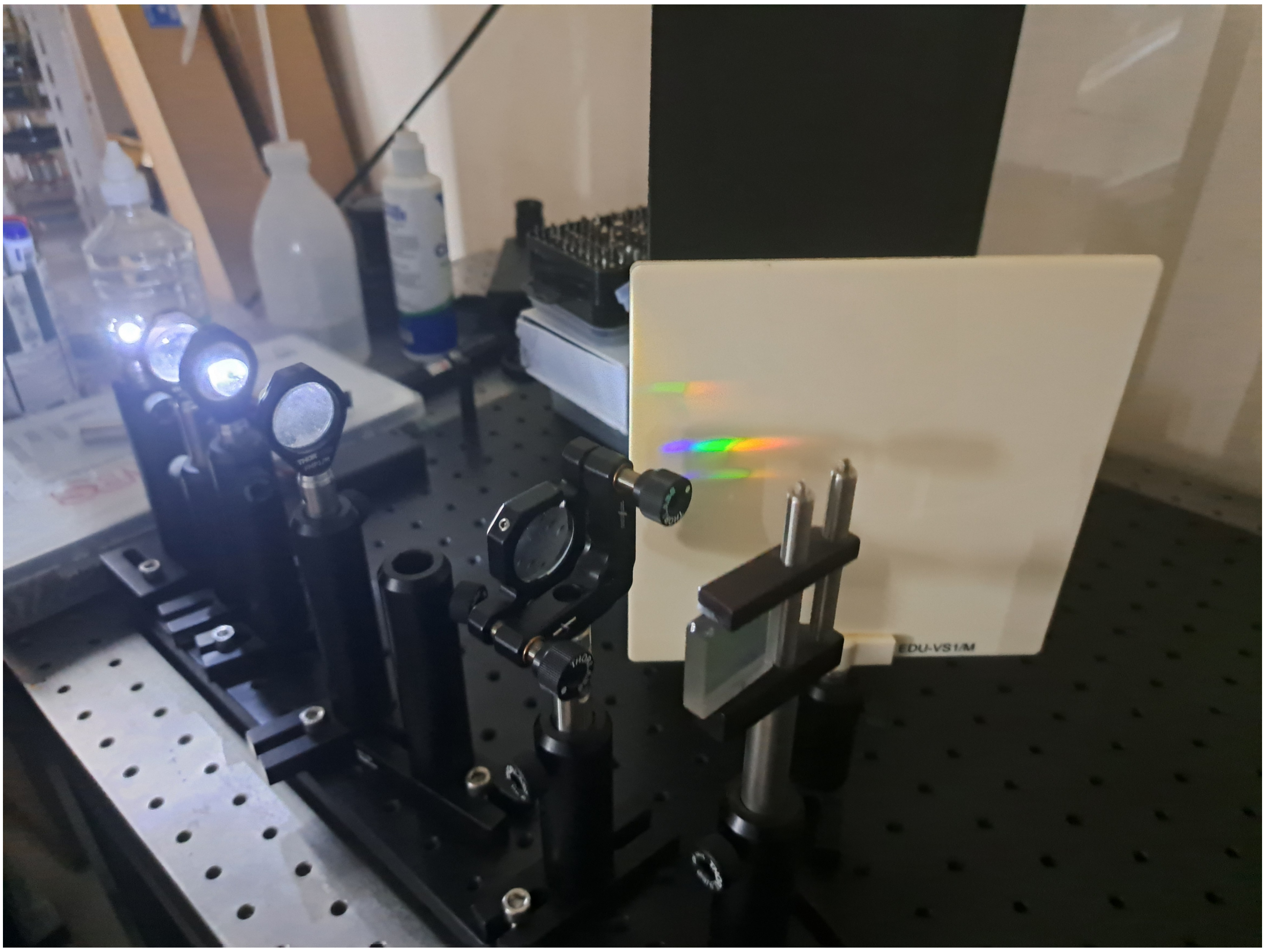


Figure 18: The spectrum on the screen from the test bench

Experiment 2

In Experiment 2, we attempted to simplify SpectrumMate by using only two lenses instead of five. We hoped this change would make it easier to set up. Simplifying the setup did indeed make the alignment process easier. However, we encountered an unexpected issue: the shape of the measurement we obtained differed from what we anticipated. Instead of a rectangle, like the shape of the slit we used to measure light, we obtained a circle.

This unexpected outcome puzzled us because we expected the measurement to match the shape of the slit. The circular shape suggested that something was causing the light to spread out in a circular pattern instead of remaining in a straight line.

Upon closer examination, we realized that the problem might stem from how the light interacted with the lenses or the grating in the setup. It's possible that the lenses or the grating were dispersing the light in such a way that it formed a circle rather than a rectangle.

This discovery prompted us to reconsider how we set up SpectrumMate and explore potential solutions to ensure that the measurement accurately reflected the shape of the slit. While Experiment 2 simplified some aspects of the setup, it also emphasized the importance of understanding how each component affects light to obtain precise measurements.

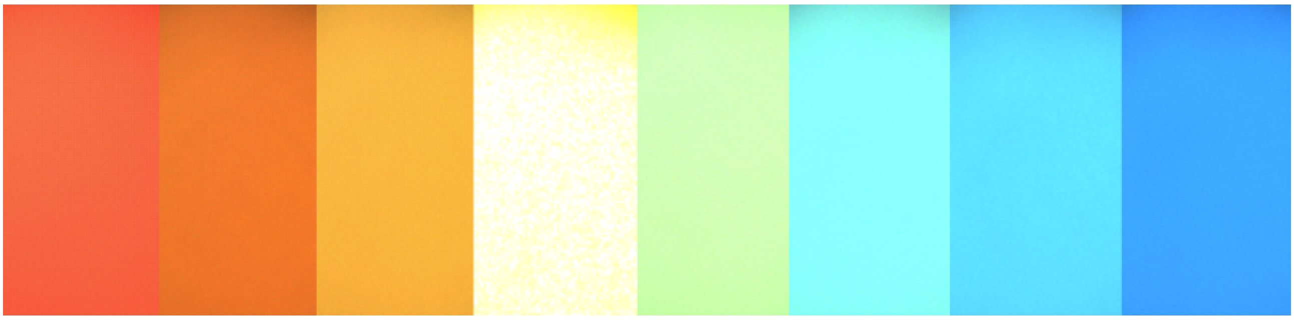


Figure 19: The spectrum on the screen from the SpectrumMate, after slicing the images