Manual

PE-0400 Diffraction of Light

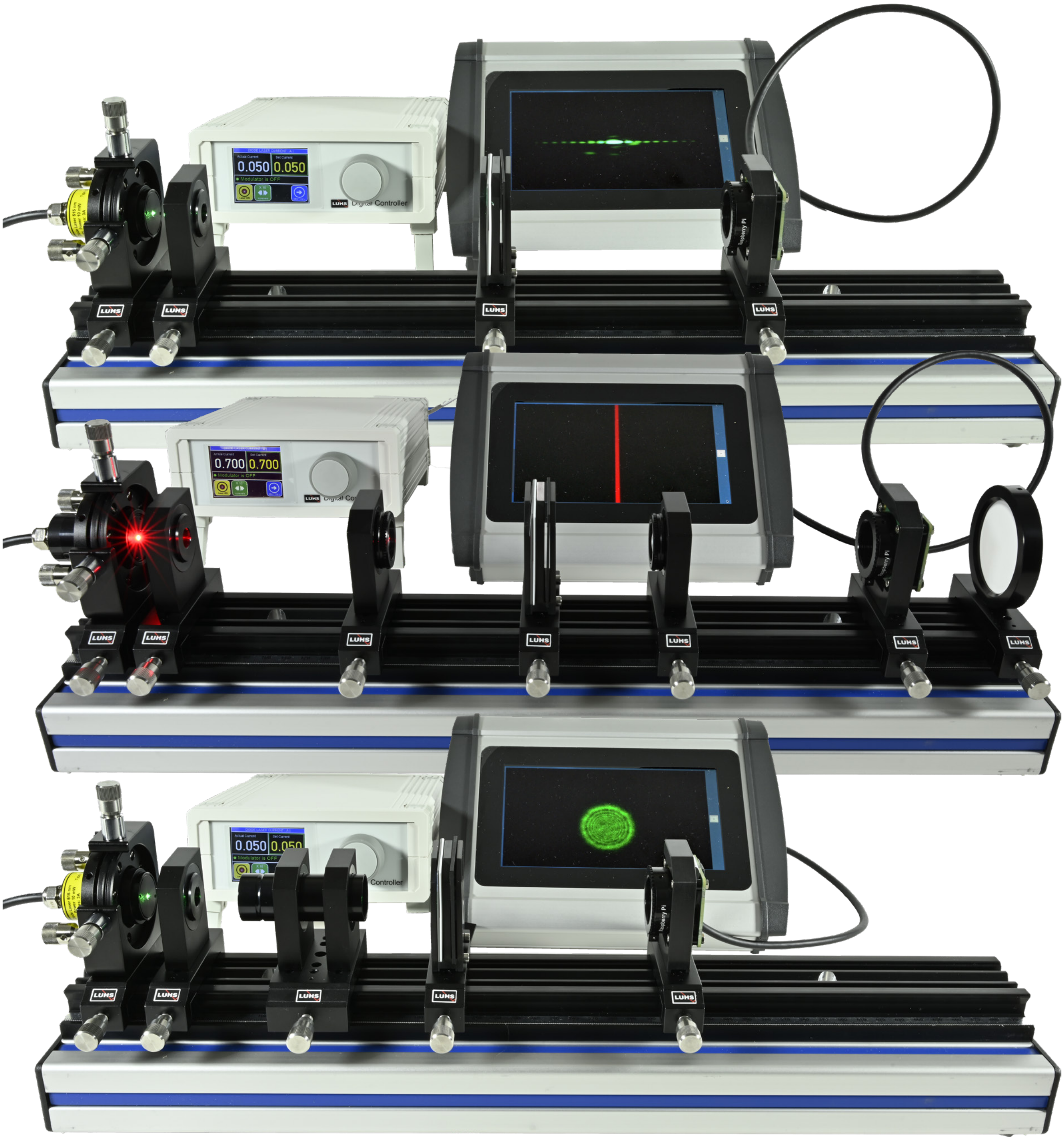


Table of Contents

1.0 Introduction

All objects that restrict the free propagation of light cause diffraction. Although this phenomenon is always present, it is often neglected because its effect is too insignificant to warrant consideration in the context of the investigation. However, if light hits sharp edges, diffraction will appear clearly and cannot be neglected, especially when light is diffracted through very narrow openings, such as holes or slits. Christian Huygens formulated his observation of diffraction in the 17th century, applying the principle of elementary waves. In 1800, Fresnel and Fraunhofer both studied the effect of diffraction in detail. Fresnel used divergent light for his investigations, whereas Fraunhofer used parallel light created by a pair of lenses. Both techniques are termed as Fresnel and Fraunhofer diffraction, respectively. This experiment offers both types of diffraction. Experiments are performed using monochromatic laser light, which will be diffracted at slits and holes of various widths. Thin wires impressively prove the Babinet theorem, which states that complementary masks (slit, wire) result in the same diffraction pattern. The obtained diffraction patterns are imaged on a white screen, and a CCD camera can also record the pattern.

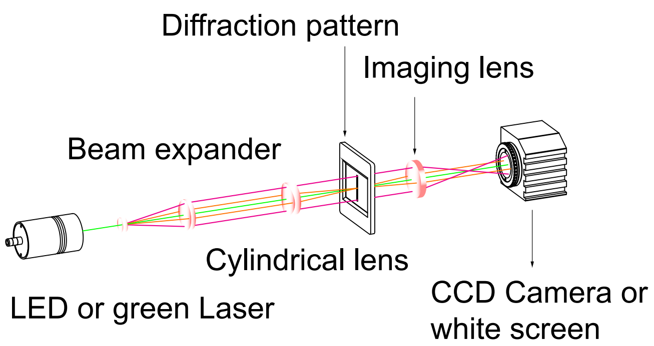


Fig. 1: Principle set-up

The experiment uses a red-emitting LED or a green-emitting laser. For both light sources, the controller provides the individual current and voltage. The controller's microprocessor reads the property of the connected light source and sets the parameter accordingly. When using the green laser and a vertical slit or wire, the beam expander is needed to create a vertical line shape in conjunction with the cylindrical lens. Different types of diffraction elements can be inserted into the plate holder. To verify Babinet's theorem, a slit and a wire with the same dimensions are used. Furthermore, the diffraction fringes, a double slit, a circular aperture, and a two-dimensional structure are created and recorded. For a first view, the translucent screen is used. The fringes on the screen are recorded by the high-resolution (13 MP) CCD camera and are displayed live on the digital video controller. The image can be taken as a still photo, as a video, or as a data file. The video controller provides USB inputs for a memory stick or other external devices like a mouse or keyboard. Initially, the translucent screen is used for a first view. The fringes on the screen are recorded by the high-resolution (13 MP) CCD camera and are displayed live on the digital video controller. The image can be taken as a still photo, a video, or as a data file. The video controller provides USB inputs for a memory stick or other external devices like a mouse or a keyboard.

2.0 Multiple beam interference

After joining the Royal Society of London in 1672, Newton stated light is made of particles and not waves.
Newton's corpuscular theory of light is based on the following points

1. Light consists of very tiny particles known as "corpuscular".
2. These corpuscles on emission from the source of light travel in straight line with high velocity
3. When these particles enter the eyes, they produce image of the object or sensation of vision.
4. Corpuscles of different colours have different sizes.

In 1679, Christian Huygens proposed the wave theory of light.
According to Huygen's wave theory:

1. Each point of a light source sends out waves in all directions in a hypothetical medium called "ETHER".
2. Light is a form of energy
3. Light travels as waves.
4. Like for sound in air a medium is necessary for the propagation of waves and the whole space is filled with such an "Ether"
5. Compared to sound, light waves have very short wave length

Already at this time the battle about the property of light was initiated. Newton enjoyed the absolute scientific authority and one can imagine what Huygens dared to claim.

"There remained one problem that Huygens theory of light could not solve. In 1669, three years before Newton first presented his particle theory of light, Danish physicist Erasmus Bartholin had begun experimenting with transparent calcite crystals that had been discovered in Iceland. He found that when an image is placed behind a crystal it is duplicated, with one copy appearing slightly higher than the other."

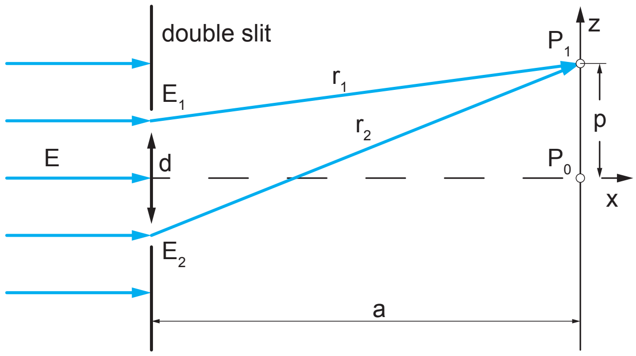


Fig. 2: Thomas Young's double slit experiment of 1802

The basic idea of the analysis of the interference is to calculate for the path difference Δ of the interfering rays. In the example of the Fig. 2 we note:

$$\Delta = r_2 - r_1$$

$$r_1^2 = a^2 + \left(p - \frac{d}{2}\right)^2$$

$$r_2^2 = a^2 + \left(p + \frac{d}{2}\right)^2$$

$$r_2^2 - r_1^2 = 2 \cdot p \cdot d = (r_2 - r_1) \cdot (r_2 + r_1)$$

$$p, d \ll a$$

$$r_1 + r_2 \approx 2 \cdot a$$

$$2 \cdot p \cdot d = (r_2 - r_1) \cdot 2 \cdot a$$

$$\Delta = r_2 - r_1 = \frac{p \cdot d}{a}$$

$$\delta = \frac{2 \cdot \pi}{\lambda} \cdot \Delta = \frac{2 \cdot \pi}{\lambda} \cdot \frac{p \cdot d}{a}$$

From the previous chapter we learned that constructive superposition occurs, when

$$\delta = 0, \pm 2\pi, \pm 4\pi, \ldots$$

and destructive interference for:

$$\delta = \pm \pi$$

$$I(z) = \begin{cases} \max & 0, \quad \pm \frac{\lambda \cdot a}{d}, \quad \pm 2 \cdot \frac{\lambda \cdot a}{d}, \ldots \\ \min & \pm \frac{1}{2} \cdot \frac{\lambda \cdot a}{d}, \quad \pm \frac{3}{2} \cdot \frac{\lambda \cdot a}{d}, \quad \pm \frac{5}{2} \cdot \frac{\lambda \cdot a}{d}, \ldots \end{cases}$$

Thomas Young performed his famous Double Slit Experiment in 1802. From his results and conclusions, it was determined that light propagates in wave form and therefore possesses the ability to interfere with itself. Young also is responsible for the principle of coherence and of superposition, two of the most fundamental principles in the fields of interferometry and optics. Thus, the wave theory of light came to be thanks to the refinement efforts of several distinguished and important people.
During the gold-rush mood of the wave nature of light a variety of observations and interference schemes came up.
Arago, Fizeau and Foucault interference of light at thin wedges (1848), almost during same time Haidinger fringes, interference of equal inclination.
In principle a lot of possible interference schemes can be conceived. To analyze such a scheme simply the superimposition of waves it is useful to identify the interfering electrical field vector $\vec{E}$.

$$\vec{E}_i = \vec{E}_a + \vec{E}_b$$

$$I(x, y, z) = \left|\vec{E}_i\right|^2 = \left|\vec{E}_a + \vec{E}_b\right|^2$$

3.0 Diffraction

In all cases where an object has nearly the same dimension of the wavelength of the light with which the object interacts, the diffraction phenomena are dominating instead of geometrical considerations.

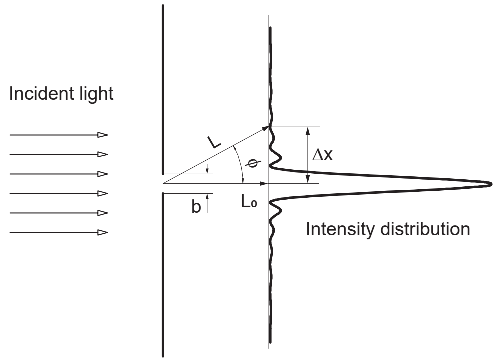


Fig. 3: Diffraction at a slit with a width of b

This becomes clear if one looks at the bottom surface of a CD, one notices the occurrence of rainbow colors. Beside that the CD also acts as a mirror. Thus we can conclude, that a CD acts as a reflecting grating. If no pits where printed to the CD it would act only as a simple mirror. To understand why the back reflected intensity of the incident laser beam is changed when it hits a bump (pit) we have to recall the diffraction at a slit.

Actually the CD has no slits, but the description of a slit with a mirror behind it is equivalent. In a first step we neglect the height of the bump. From basic physics textbooks we learn that the intensity distribution of the light behind a slit can be written as:

$$I(\phi) \sim b^2 \cdot \frac{\sin^2\left(\frac{\pi \cdot b}{\lambda} \cdot \sin\phi\right)}{\left(\frac{\pi \cdot b}{\lambda} \cdot \sin\phi\right)^2}$$

(Eq 1.1)

If the width of the slit b is large compared to the wavelength λ of the incident beam we will obtain an intensity distribution as shown in Fig. 4 A. When we are going to decrease the width of the slit towards b=λ we will get an intensity distribution like Fig. 4 B. For the case of the CD we can conclude that due to the now broad intensity distribution only a small part of the back reflected light will enter the aperture of the pick-up optics resulting in a reduction of the reflected intensity. The light which shines beside the bump is simply reflected back and enters without change of direction and intensity the pick-up optics. Both the reflected light from the bump as well the light around it are in phase. If we introduce a phase shift of 90° (λ/2) between both light beams destructive interference occurs resulting in a further decrease of the back reflected light intensity. For this reason the height of the reflecting bump is chosen to be λ/4.

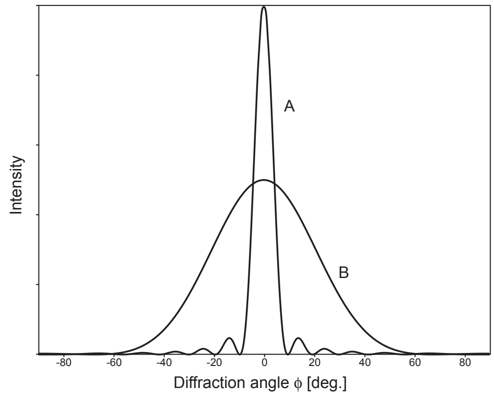


Fig. 4: Intensity distribution for a width of the slit A) b = 6 λ and B) b = λ

In summary the change of back reflected intensity when the laser beam hits a bump is due to diffraction and interference. In the next fig. 2.40 the situation is shown to illuminate the phenomena of interference.

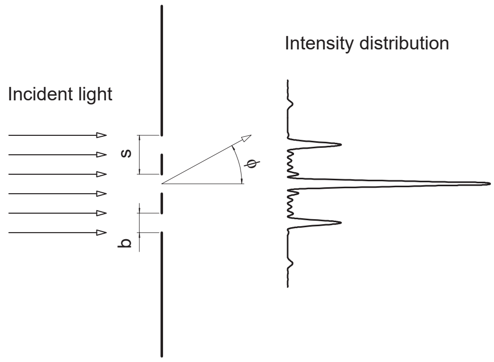


Fig. 5: Diffraction with two slits having a width of b and a distance of s

If we are going to increase the number p of slits the intensity distribution behind the slit can be expressed as:

$$I(\phi) \sim \frac{\sin^2\left(\frac{\pi \cdot b}{\lambda} \cdot \sin\phi\right)}{\left(\frac{\pi \cdot b}{\lambda} \cdot \sin\phi\right)^2} \cdot \frac{\sin^2\left(\frac{\pi \cdot p}{\lambda} \cdot s \cdot \sin\phi\right)}{\sin^2\left(\frac{\pi}{\lambda} \cdot s \cdot \sin\phi\right)}$$

In Fig. 6 this function is represented. For a given wavelength λ the grating can be optimized in such a way that the intensity distribution now consists of three distinct maxima.

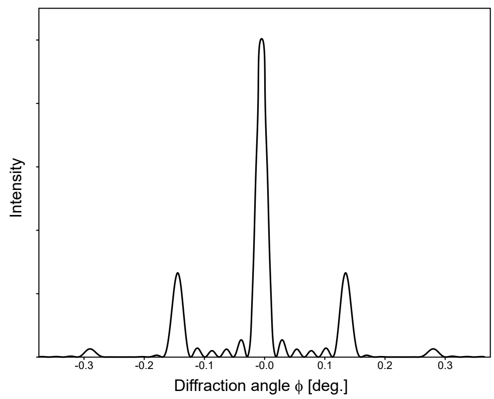


Fig. 6: Three beam intensity distribution generated by a for this purpose designed grating

4.0 Description of Components and Setup

In this experimental set-up for investigating the diffraction of light, we use two different set-ups. In one set-up we use the digital camera with a lens and image the diffraction pattern of the observation screen. In the second setup, the digital camera is used both as an observation screen and as an image sensor.

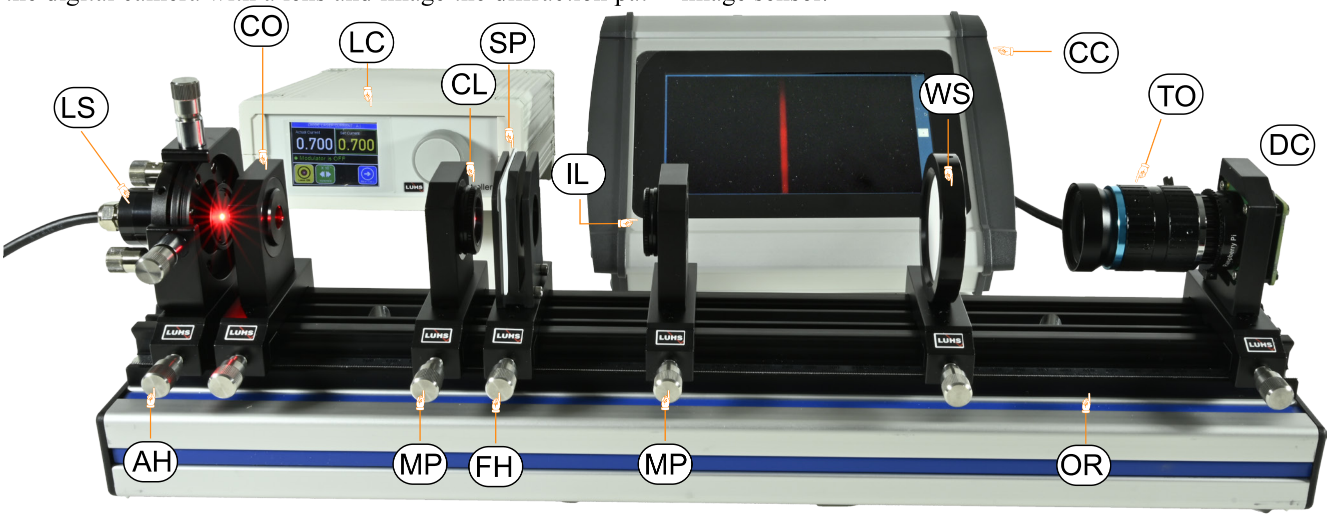


Fig. 7: Setup with observation screen (WS) and camera with telephoto lens (TO)

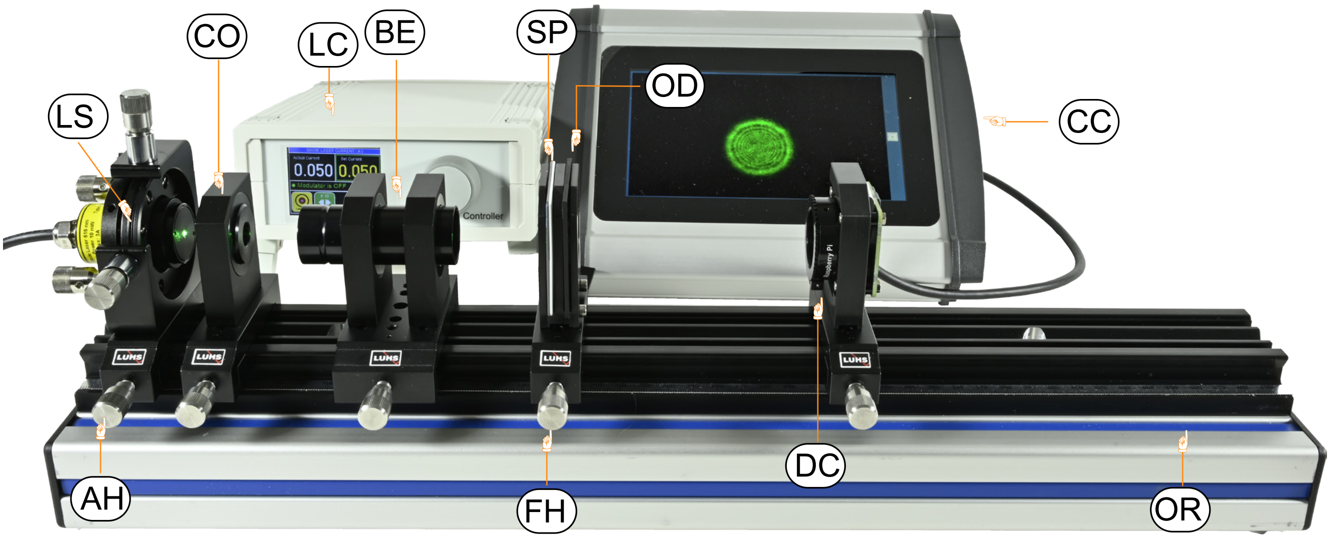
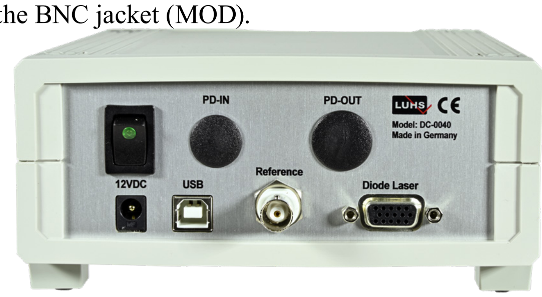


Fig. 8: No screen (WS) and camera lens (TO) are used in this setup. The CCD chip of the camera serves as a screen and image sensor.

AH Adjustment Holder	**LS** Light Source	**CO** Collimator
LC Diode Laser Controller	**BE** Beam Expander	**SP** Diffraction Specimen
OD Neutral Density Filter	**CL** Cylindrical Lens	**IL** Imaging Lens
FH Filter Plate Holder	**DC** Digital Camera	**OR** Optical Rail
MP Mounting Plate	**TO** Telephoto lens	

4.1 (LC) LED and Laser Controller

The controller is operated by a touch screen and a digital potentiometer with a knob. The laser diode module is connected via the 15 pin HD SubD jacket (LD). The controller reads the EEPROM of the laser diode and sets the required parameter accordingly. The MK1 is powered by an external 12V/ 1.5 A wall plug supply. The MK1 provides an internal modulator which allows the periodic switch on and off the diode laser. A buffered synchronization signal is available via the BNC jacket (MOD).

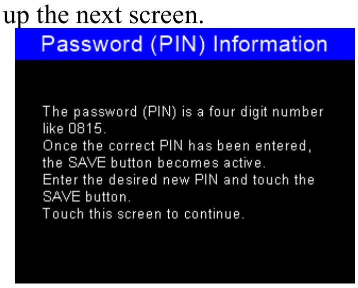


The back side of the controller has the connector for power (12V 1A, a power supply is provided), the Reference modulation signal, the 15 pin HD SubD connector for the laser diode.

When the external 12 V is applied, the controller starts displaying the screen as shown in the figure below.

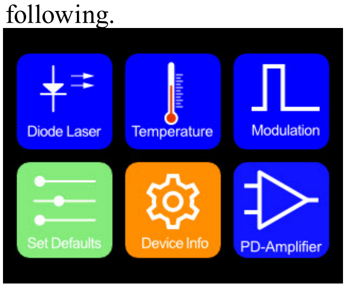
The first interactive screen requires the log in to the device since due to laser safety regulations unauthorized operation must be prevented.

In general, this is accomplished by using a mechanical key switch. However, this microprocessor operated device provides a better protection by requesting the entry of a PIN. After entering the proper PIN, the next screen is displayed, and the system is ready for operation. Touching the "HOW TO?" brings up the next screen.

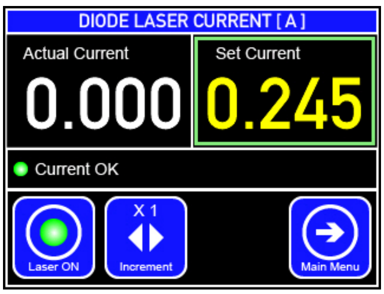


The appearing text explains how to change the default password.

After the correct password has been entered, the main screen is activated. It shows the buttons for the current settings of the attached diode laser, its temperature and modulation. Furthermore, the photodiode amplifier, the device info, and a Set to Defaults" button. The individual functions are explained in the following.

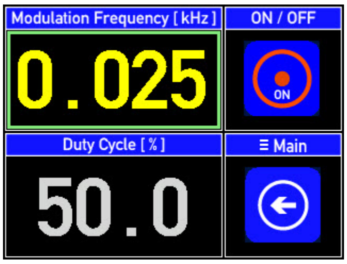


Diode Laser or LED Settings



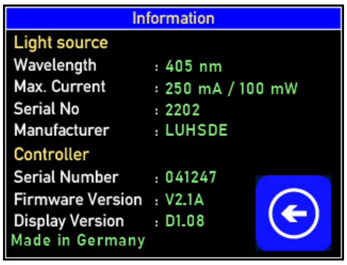
To change the set current of the diode laser, touch the "Set Current" window. Once activated it is framed with a green border. By turning the settings knob (SET) the desired value is selected. For faster settings of the current in 10 mA instead of 1 mA the increment button is touched. Touch the "LASER ON" to switch the laser on. The PID controller is activated and drives the laser slowly to the desired value. This may take a few seconds to reach the set value. For immediate "Laser OFF" just touch Laser ON button.

Modulation Settings



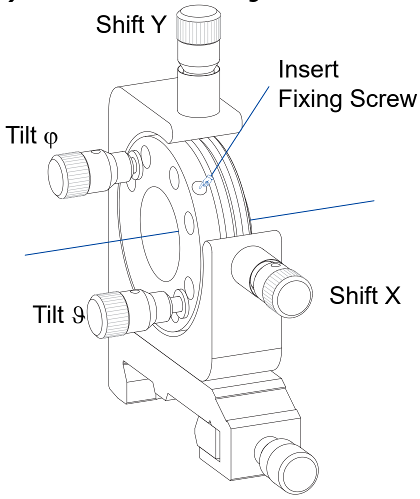
The LED or laser can be switched periodically on and off. This is for a couple of experiments of interest. By tapping the display of the modulation frequency, the entry is activated. Turning the settings knob will set the desired frequency value. The modulation becomes active when the Modulator ON/OFF button is tapped. For some experiments it is important to keep the thermal load on the optically pumped object as low as possible or to simulate a flash lamp like pumping. For this reason, the duty cycle of the injection current modulation can be changed in a range of 1...100 %. A duty cycle of 50% means that the OFF and ON period has the same length. The set duty cycle is applied instantly to the injection current controller.

This screen is self-explanatory and appears either when no laser diode is connected or the data reading from the EEPROM is erroneous.



The diode laser module or LED is connected via the 15 pin HD SubD jacket at the rear of the controller. The controller reads the EEPROM of the laser diode and sets the required parameter accordingly. This information and some more information about the controller are shown on the info screen.

4.2 (AH) Four axes adjustment holder



This frequently needed component is ideal for the fine adjustment of lenses, microscope objectives, diode laser, and so on for the optical axis of the rail set-up. The displacement area is 5x5 mm and 10x10 degrees, respectively. Different mounts can be attached to the adjustment holder. This model provides a holder for 25 mm cylindrical components. The component is inserted into the adjustment holder and is kept in position by a grub screw with a nylon tip. Four precise fine-pitch screws of repetitious accuracy allow the translational (X; Y) and azimuthal (υ; φ) adjustment.

4.3 (LS) The Light Sources

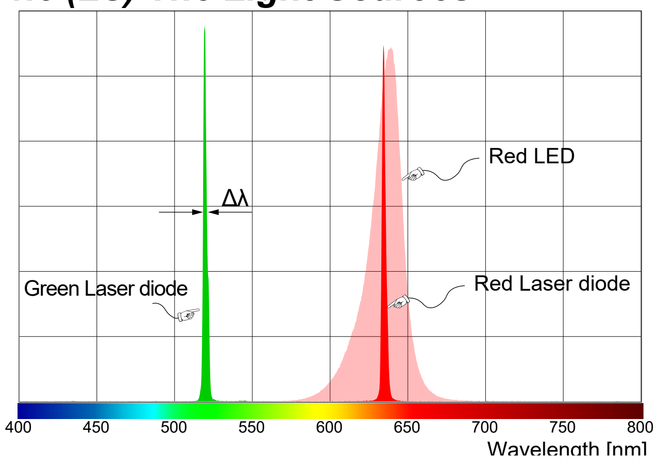


Fig. 9: Emission spectra of the used light sources

In this experiment we will use three different light sources, an LED emitting in the red spectral range, a laser diode emitting at 515 nm and a red emitting at 638 nm. Using a spectrometer with a resolution of 1 nm, we measured the spectra of the three light sources and displayed them in Fig. While the LED has a broad emission (dL), the laser diodes have a much narrower emission width. The narrower the emission line width, the higher the coherence and the associated coherence length. In the following experiments, we will not be able to detect any diffraction phenomena due to the lack of coherence of the LED.

4.3.1 Red Light LED

Fig. 10: Red LED in ø 25 Housing

A red light LED is built into a round housing (C25). The LED is connected via a 15 pin SubD HD connector to the controller MK1. Inside the connector an EPROM contains the data of the LED and when connected to the controller, these data are read and displayed by the controller.
The corresponding emission spectrum is shown in Fig. 9. The emission width Δλ is comparatively broad compared to the spectrum of the laser diodes.

4.4 Green Laser

Fig. 11: Green (515 nm) Laser diode

A laser diode that emits in the green spectral range is installed in a round housing with a diameter of 25 mm. The peak wavelength is 515 nm and the emission is single transverse mode. The associated line width Δλ is very narrow compared to the red LED. The maximum output power is 10 mW and belongs to laser class 3A, and the corresponding safety regulations must be observed. For operation, the laser diode is connected to the control unit and inserted into the holder. The side grub screw with a nylon tip secures the laser in the holder.

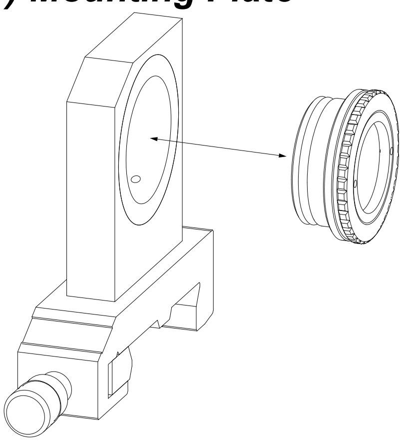
Fig. 12: Light source mounted into the 4-axes adjustment holder

The laser is connected via a 15 pin SubD HD connector to the controller. Inside the connector an EEPROM contains the data of the laser diode and when connected to the controller, these data are read and displayed by the controller.

Fig. 13: Red Laserdiode

A laser diode that emits in the red spectral range is installed in a round housing with a diameter of 25 mm. The peak wavelength is 638 nm and the emission is single transverse mode. The associated line width Δλ is very narrow compared to the red LED, see Fig. 9. The maximum output power is 10 mW and belongs to laser class 3A, and the corresponding safety regulations must be observed. For operation, the laser diode is connected to the control unit and inserted into the holder. The side grub screw with a nylon tip secures the laser in the holder.

4.5 (MP) Mounting Plate



This frequently used component is ideal to accommodate parts with a diameter of 30 or 25 mm where it is kept in position by three spring loaded steel balls. Especially C25 or C30 mounts having a click groove are firmly pulled into the mounting plate due to the smart chosen geometry. The mounting plate is mounted to a 20 mm wide carrier.

4.6 (BE) Beam Expander

Beam Expander x6 in ø25 housing

The beam expander is based on a Galilean telescope with one concave lens as entry lens and a plano-convex as exit lens. The expansion ratio is defined by the ratio of the focal length of the lenses. The entry lens is mounted into a C25 mount which screwed to the 25 mm housing at which end the exit lens is mounted. This beam expander has an expansion rate of 6. The telescope is aligned for far sight view and can be slightly changed by turning the C25 mount to change the parallel wave front into curved ones.

The beam expander is used to enlarge the laser beam to provide an almost parallel beam of coherent light.

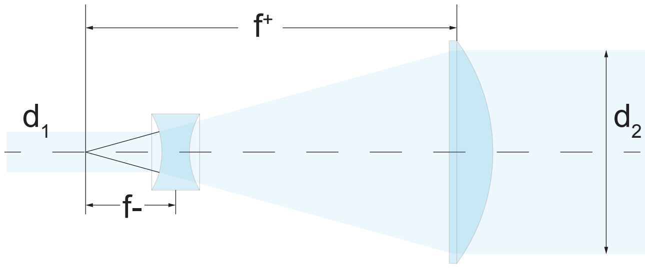
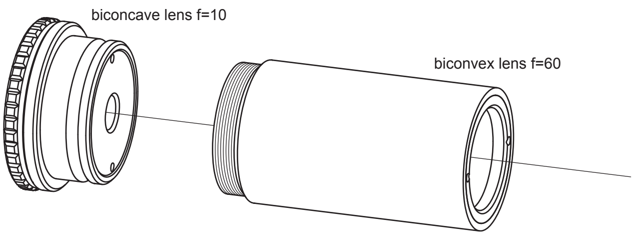


Fig. 14: Galilean beam expander

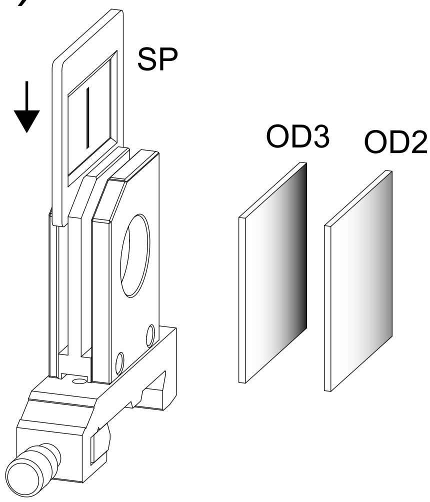
Expansion ratio or magnification:

$$\frac{d_2}{d_1} = \frac{f^+}{f^-}$$



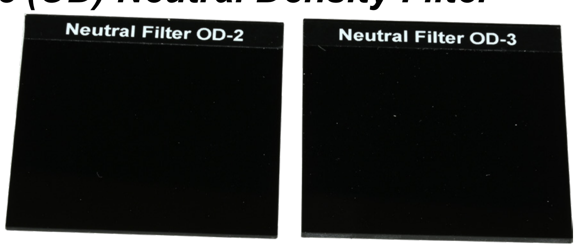
The provided beam expander consists of a combination of a biconcave (f=-10) and biconvex lens (f=60) forming the so called Galilean beam expander with a magnification of 6. The beam expander can be separated in such a way that the lenses can be used independently.

4.7 (KH) Plate holder



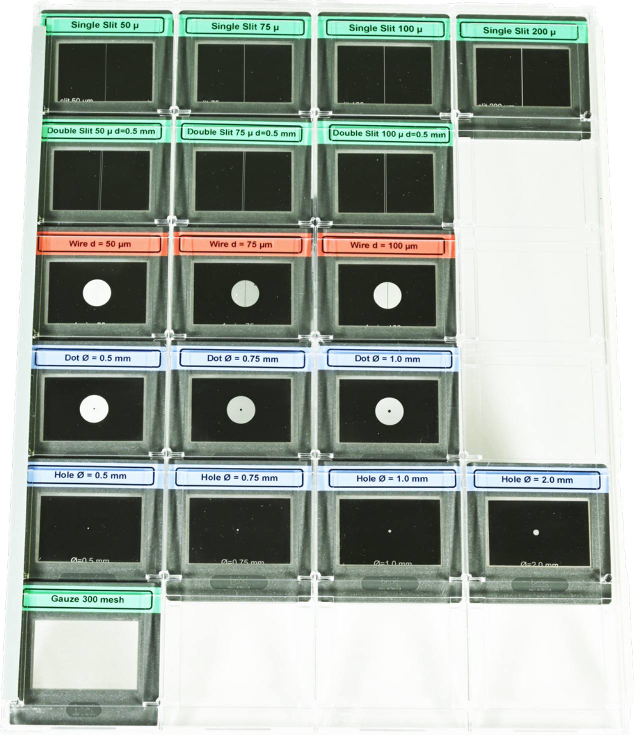
This filter plate holder is designed to accommodate standard optical plates with a thickness of 3 mm, a width of 50 mm and a height of 50 mm. .

4.8 (OD) Neutral Density Filter



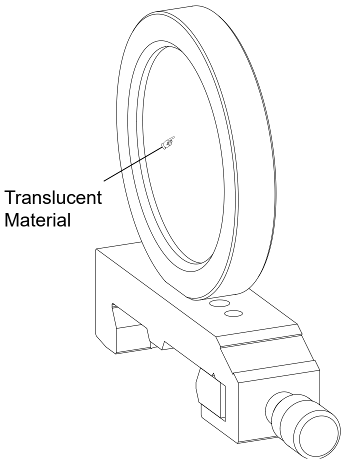
If the lighting values override the camera, neutral attenuators, so-called neutral density filters, are used. Two different filters are used, one with an optical density OD of 2 and one with an optical density OD of 3.

4.9 (SP) Diffraction Specimen



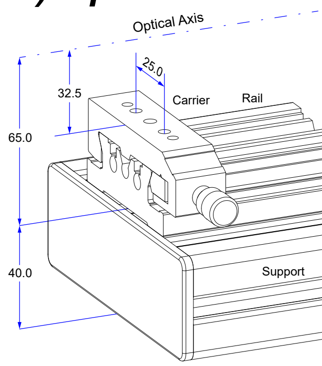
Various objects are used for the diffraction experiments. It starts with simple slits with a width of 50, 75, 100 and 200 µm. This is followed by double slits with a distance between the slits of 0.5 mm and a slit width of 50, 75 and 100 µm. Wires with a width of 50, 75 and 100 µm are used as counterparts to the single slots. To verify Babinet's theorem, points and holes with a diameter of 0.5, 0.75 and 1 mm are used.

4.10 (WS) Translucent White Screen



In a round holder a sheet of translucent paper is fixed with a retaining ring. This component is useful to image and visualize optical rays. Furthermore, the translucence allows the convenient photographic recording from the opposite side with digital cameras for a quick picture for the students measurement report.

4.11 (OR) Optical Rail



The rail and carrier system provides a high degree of integral structural stiffness and accuracy. Due to this structure, it is a further development optimized for daily laboratory use. The optical height of the optical axis is chosen to be 65/105 mm above the table surface. The optical height of 32.5 mm above the carrier surface is compatible with all other systems like from MEOS, LUHS, MICOS, OWIS and LD Didactic. Consequently, a high degree of system compatibility is achieved. The attached support elevates the working height above the table and significantly improves the handling of the components.

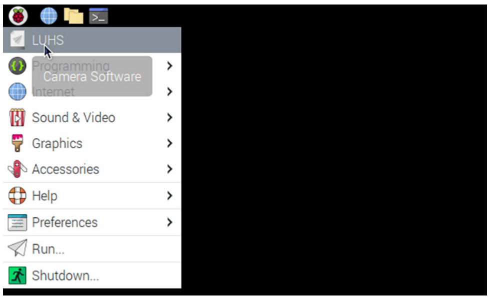
4.12 (CC) Camera Controller

The camera controller uses a Raspberry Pi 4 computer with the standard Linux distribution. The display is the recommended Raspberry 7-inch display.

The communication ports of the Raspberry PI are located at the rear of the housing, like USB 2.0 and USB 3.0, as well as network access. The camera will be connected via a mini HDMI connector.

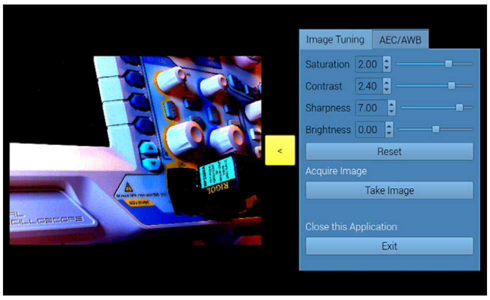
For the operation of the camera controller, the USB-C connector is provided to connect to an external wall plug power supply. Connect the provided mouse and keyboard to the USB 2.0 ports. The Raspberry PI boots to the desktop screen once the camera and the USB-C power supply are connected. In the start menu, you will select the "LUHS" application. The code is written in Python and is located in the folder home/LUHS/Camera.

Experimental setup

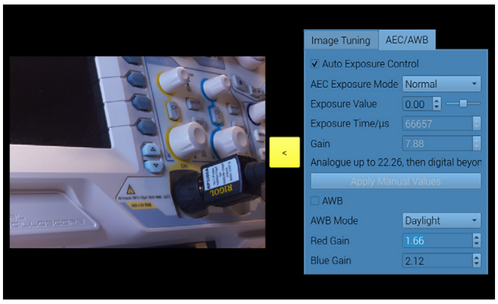


Select and run the application "LUHS" in the start menu

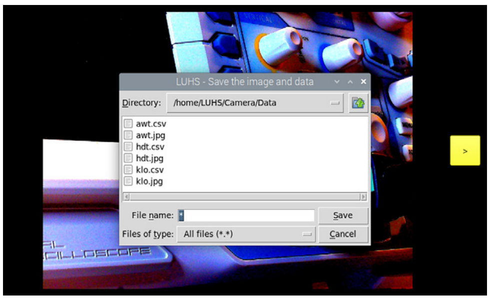
The screen shows the camera pictures and a yellow button. A click on it will shift the settings tabs into the scene.



The settings tabs are divided into two sections. One is used to manipulate the image properties like saturation, brightness, contrast, and sharpness.

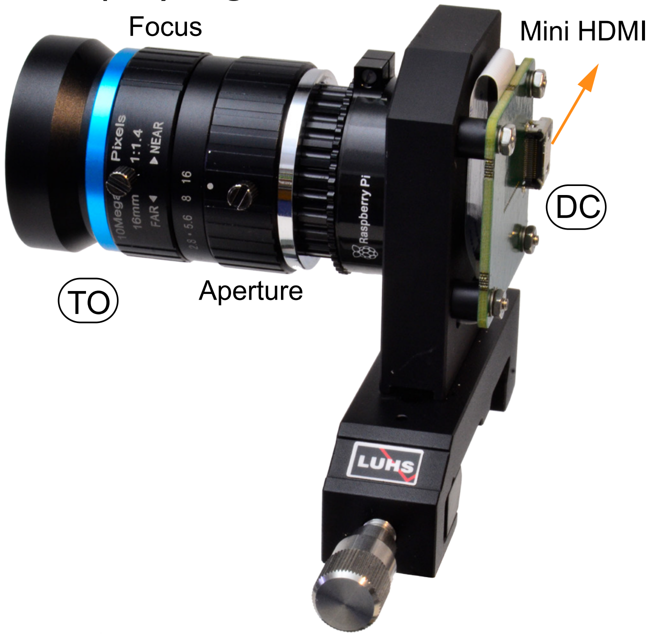


The other relates to AEC (Automatic Exposure Control) and AWB (Automatic White Balance), providing a wide variety to find the best setting for the image.



After finding the optimum image settings, the image can be saved to the camera controller's memory or an attached USB stick. Besides the jpeg image file, a CSV data file is created and stored. The CSV data file contains the intensity for each pixel (4056 x 3040) of the CCD chip of the camera. The CSV file allows the latter numerical evaluation of the image.

4.13 (DC) Digital Camera



The official Raspberry 12 MB camera is integrated into a housing attached to a carrier. The center of the chip is in line with the optical axis of the setup. The camera chip is connected via a mini HDMI cable to the controller. The objective is optimized for the CCD chip and has focus and aperture adjusting rings. The camera uses the Sony IMX477R chip with a pixel size of 1.55 µm × 1.55 µm. The entire sensor has a 7,564 × 5.476 mm dimension, having 4056 ×3040 separate pixels.

5.0 Setup and Measurements

5.1 Setup with the red LED

We start the investigations and measurements with the set-up with observation screen and camera with telephoto lens.

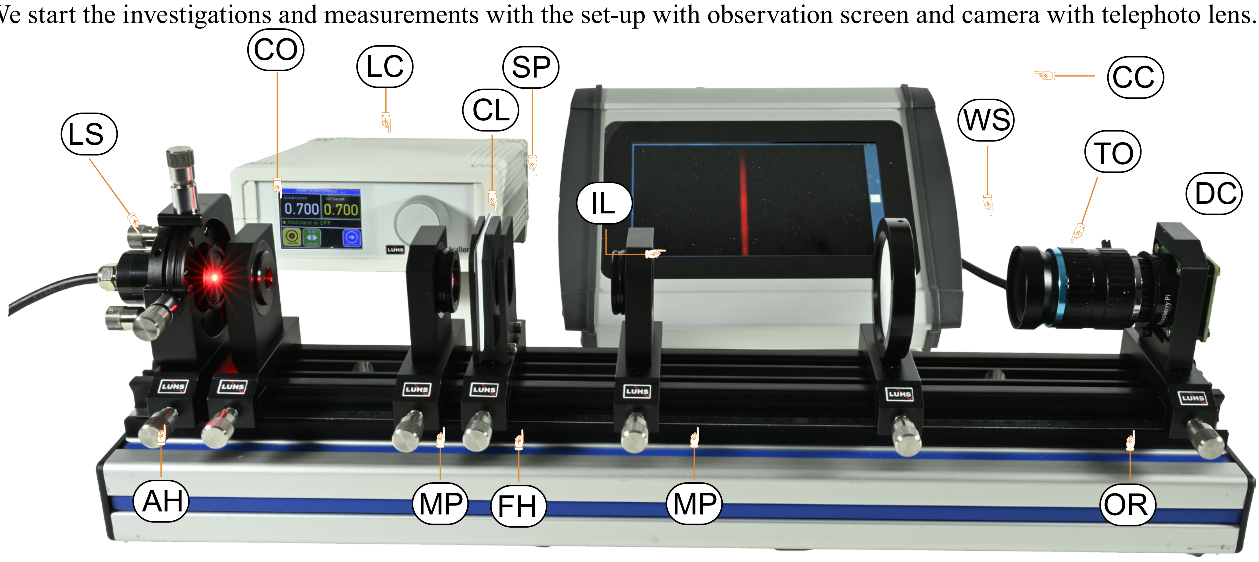


Fig. 15: Setup with imaging screen (WS) and telephoto lens

In this setup, the red LED (LS) is used, which is installed in the adjustment holder (AH). The collimator (CO) collimates the light from the LED into an almost parallel beam. The cylindrical lens (CL) shapes the beam elliptically so that the longitudinal axis of the generated ellipse illuminates the slit of the sample (SP) well. The diffraction image is imaged on the screen (WS) with the imaging lens (IL). The telephoto lens (TO) is adjusted so that the diffraction image on the screen is sharply imaged on the CCD chip of the camera (DC).

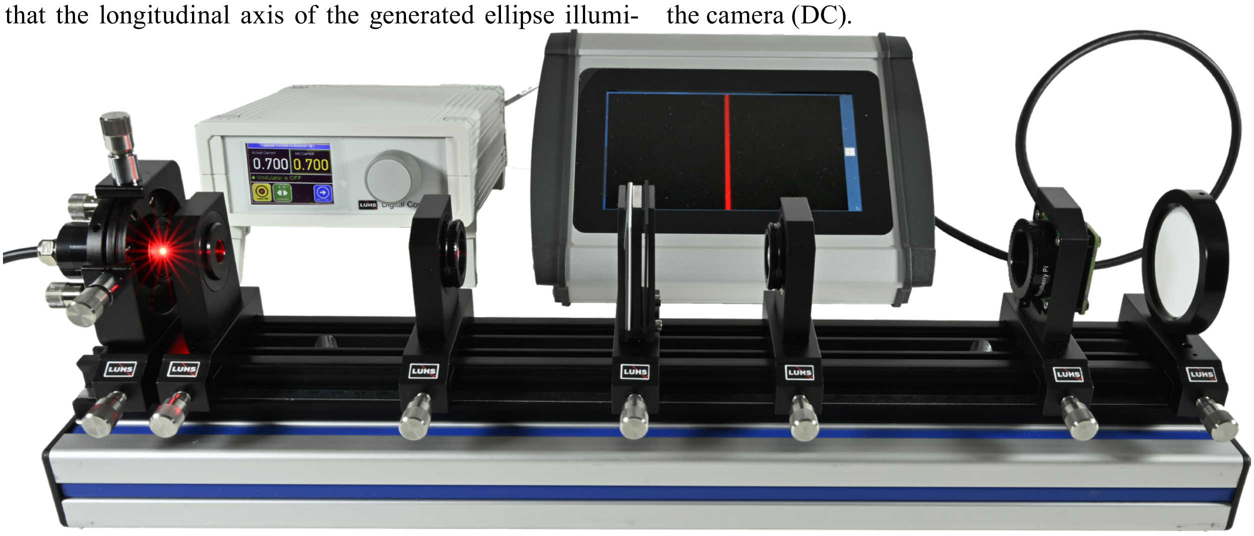


Fig. 16: Setup for direct imaging to the CCD chip of the camera (DC)

The same setup as in Fig but without image screen and telephoto lens. The distances between the cylindrical lens (CL) and the diffraction specimen are selected so that the specimen is optimally illuminated. To achieve a sharp image on the camera chip, the position of the imaging lens (IL) is varied. In both setups, we do not find any structures in the diffraction image.

So far, we have yet to discuss the prerequisites for the appearance of diffraction or interference. We assumed the incident light has just one sharp wavelength L in all related equations. However, only a coherent light source like the laser comes close to this assumption. Looking at (Eq 1.1), we notice that the intensity maxima shifts for another wavelength, and if we consider a large number of wavelengths, the structure smears out. No diffraction structure is visible any longer.

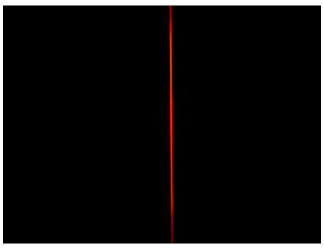


Fig. 17: 1 x 50 µm slit

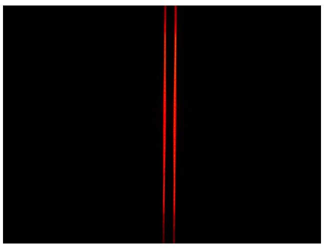


Fig. 18: 2 x 50 µm slit d=0.5 mm

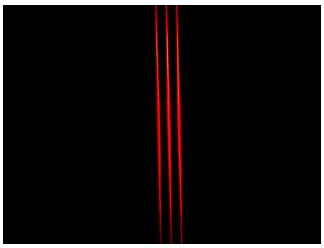


Fig. 19: 3 x 50 µm slit d=0.5 mm

Experimental setup

The fig 12-14 show the image of the slits when illuminated with a red LED. No diffraction patterns are visible; only the slit as such is imaged. The width of the slit is 0.050 mm, and if there is more than one, the distance to each other is 0.5 mm. We get a precise calibration procedure for the camera image using this information and the given dimensions of the CCD chip.

5.2 Setup with the green Laser diode

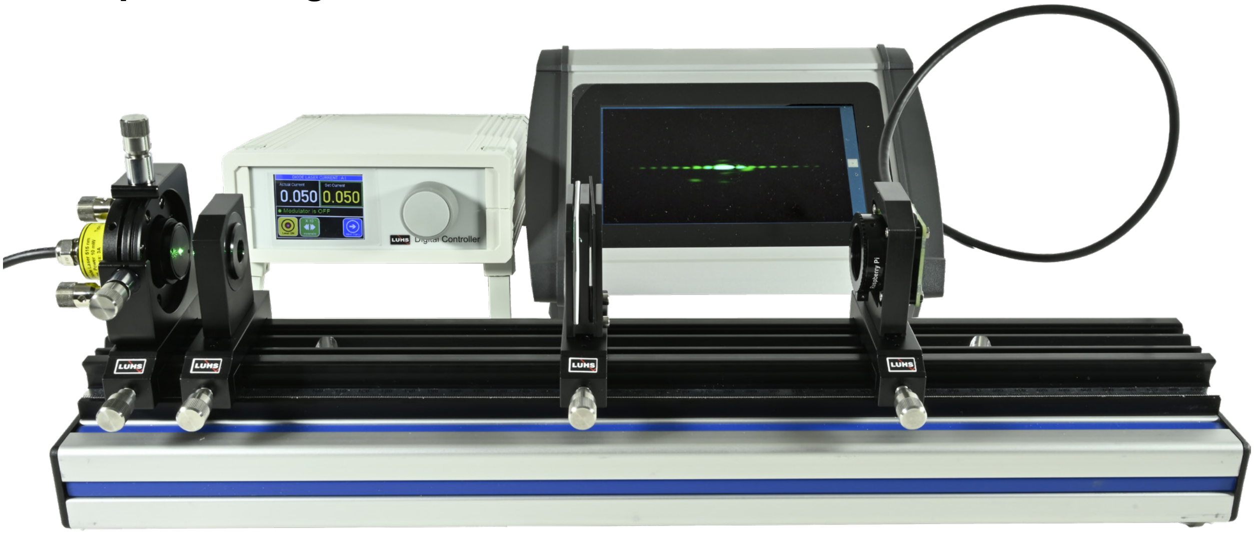


Fig. 20: Setup using the Laser diode

In this setup, we use the green laser diode instead of the red LED. The collimator (CO) is positioned so that an almost parallel beam is created. Unlike the red LED, the beam diameter is much smaller, around 2-3 mm. The beam is aligned coaxially to the optical axis of the camera using the adjustment screws of the holder (AH). This is best observed on the screen of the camera control unit (CC). To do this, reduce the power of the laser diode with the current setting of the control unit (LC) or insert attenuation filters into the plate holder (FH). In contrast to the red LED, we now see an interference structure of the diffraction image. By varying the distances between the imaging optics and the camera, the display on the screen of the camera control unit can be optimized. The intensity of the image is first set using the software. If this is not sufficient, OD 2 or OD 3 attenuation filters can be used. Once you have achieved an image of the desired quality, you can save it for later evaluation.

5.3 Setup with beam expander

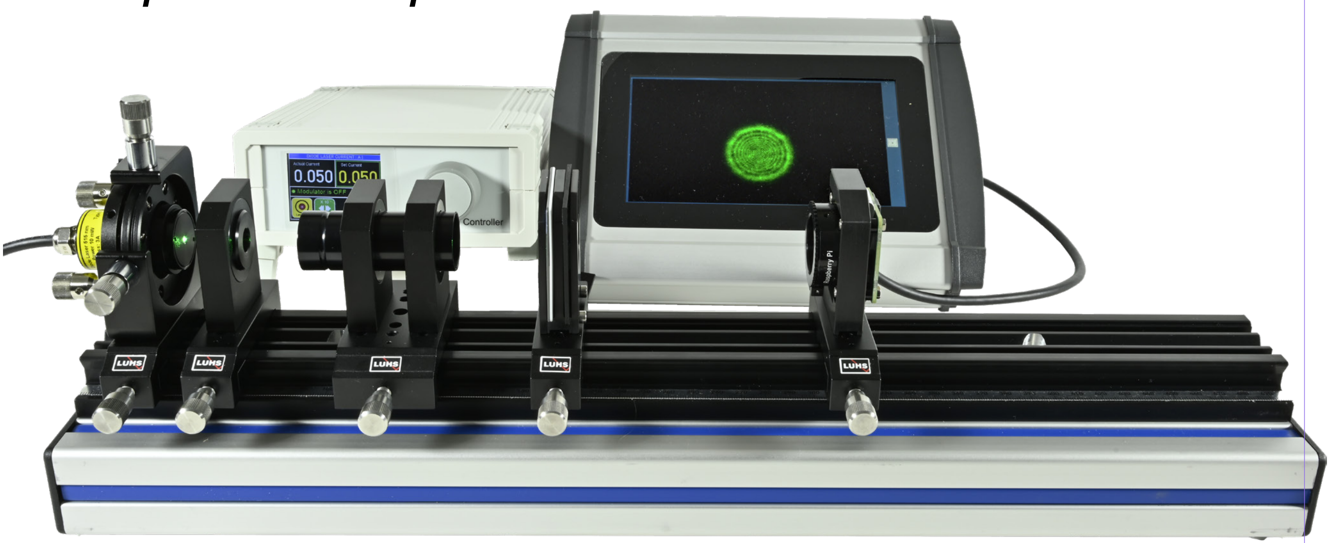
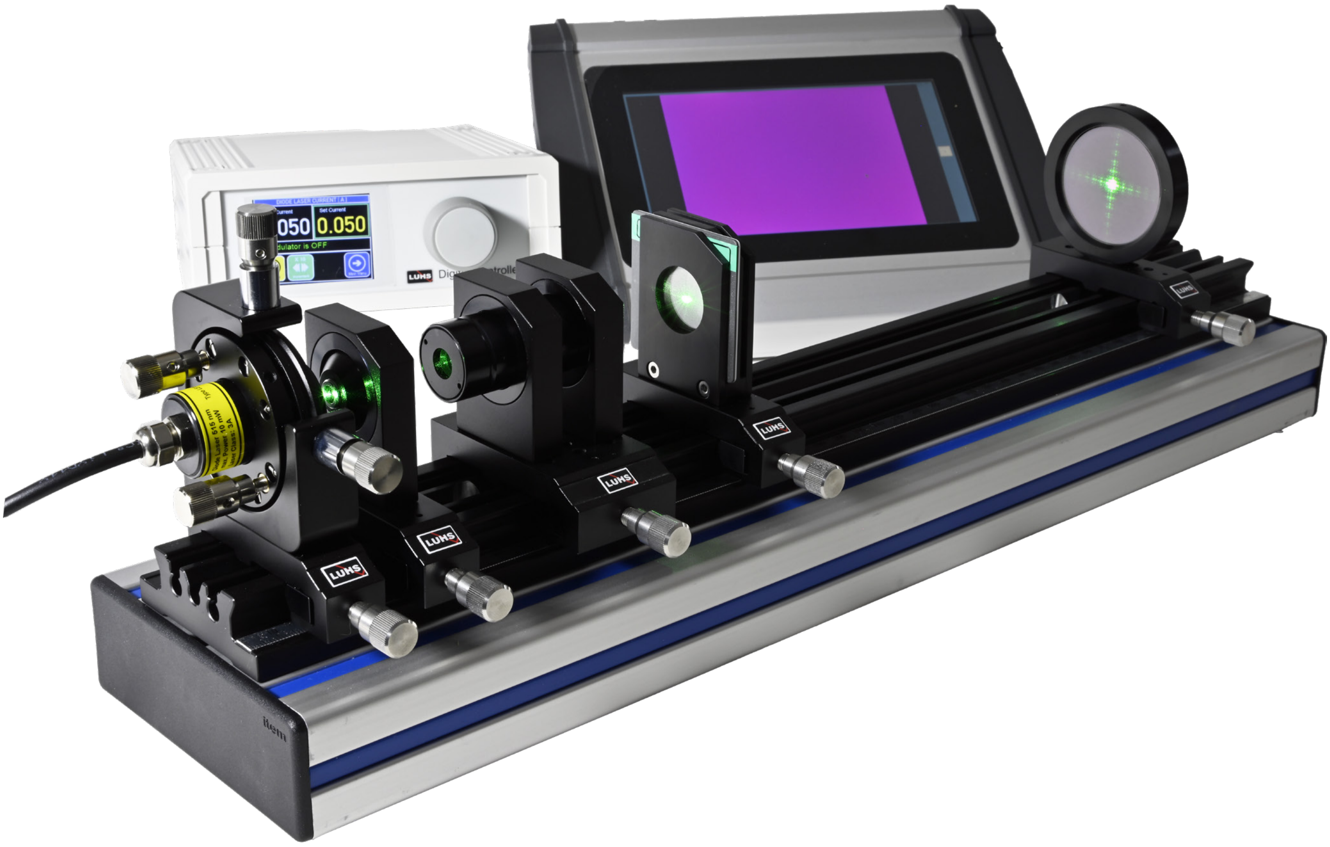


Fig. 21: Expanding the Laser beam

If the dimension of the diffraction sample is larger than the beam diameter, we use the beam expander. The beam expander has an expansion ratio of 1:6 so that the expanded beam has a diameter of about 12 mm.

Measurements

5.4 Experiments with 2D Diffraction Specimens



In this setup, a two-dimensional diffraction element, a fine-mesh gauze () with 300 mesh, is inserted into the expanded parallel beam. In this example, the screen is used for visualization instead of the CCD camera. You can change the distance to the screen or make the parallel laser beam divergent with the beam expansion telescope and observe the variations on the screen. The green emitting laser diode was used in this setup. A measurement with the CCD camera and the red emitting laser diode is shown on page 16.

5.5 Measurement Examples and Image analysis

As mentioned, saving an image, a JPEG graphics file is saved, and the intensity matrix is written into a CSV file. The Fig. 22 shows the content of the JPEG image, whereas the Fig. 23 shows the intensity distribution calculated from the CSV file.

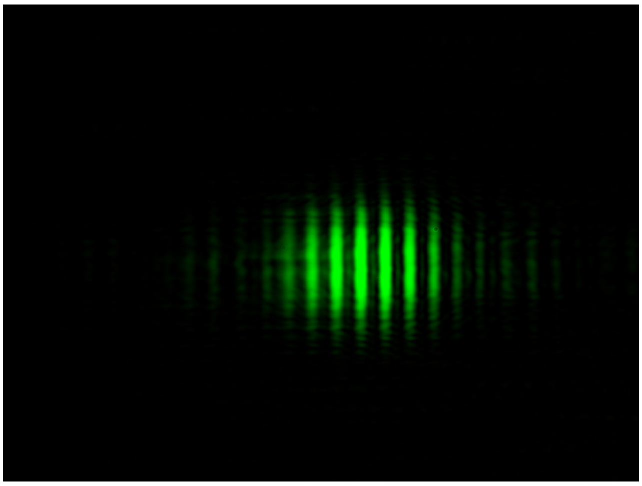


Fig. 22: Image of the saved JPEG file

There are a variety of software available to evaluate numerical data. Everybody has their favorites. MatLab, for instance, is often used. In our case, we made a short program written in Visual Basic.

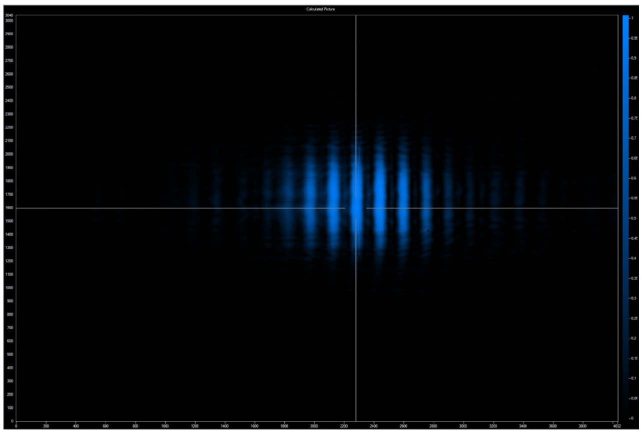


Fig. 23: Content of the CSV matrix file

The CSV file does not contain any color information. Each matrix element gives the intensity in values from 0 to 255 of the selected pixel. Any other color to display the intensity distribution can be selected.

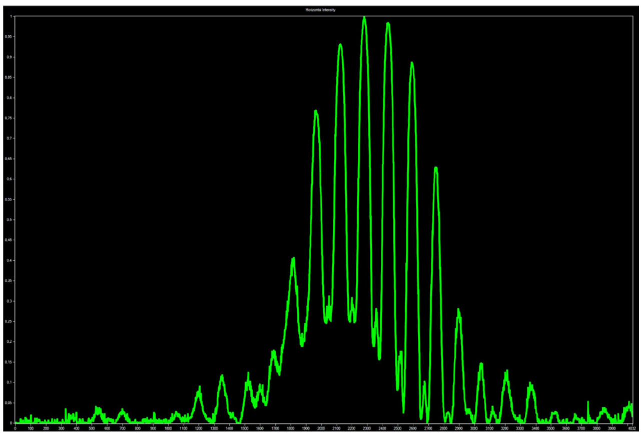
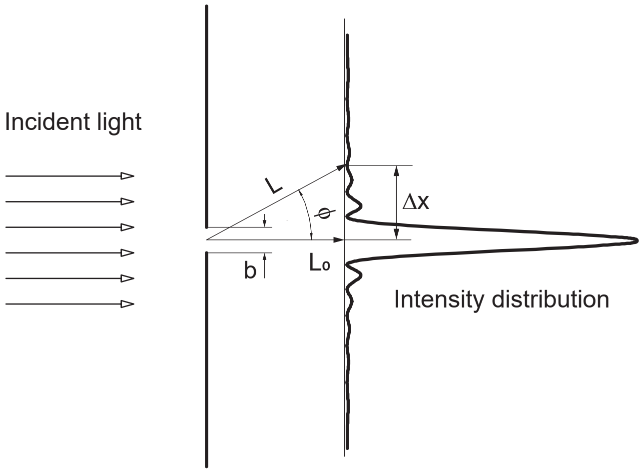


Fig. 24: Intensity distribution of the horizontal axis of Fig. 23

The values of the X-axis range from 0 to 4032 and represent the pixels of the CCD chip in the horizontal direction. The width of the active CCD chip is 7.564 mm and the height is 5.476 mm. This provides a high-precision length measurement. For example, 100 pixels are 0.188 mm.



$$I(\phi) \sim b^2 \cdot \frac{\sin^2\left(\frac{\pi \cdot b}{\lambda} \cdot \sin\phi\right)}{\left(\frac{\pi \cdot b}{\lambda} \cdot \sin\phi\right)^2}$$

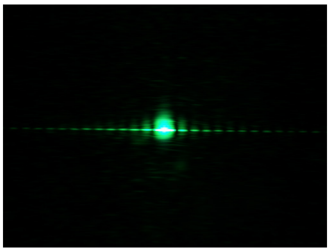
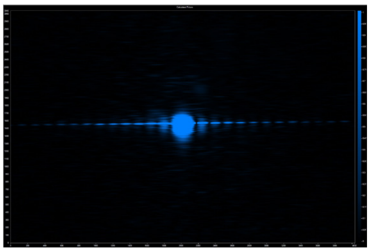
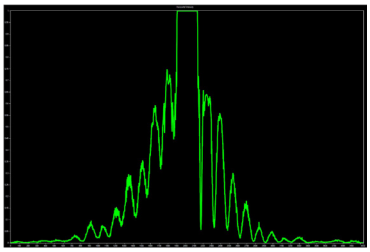
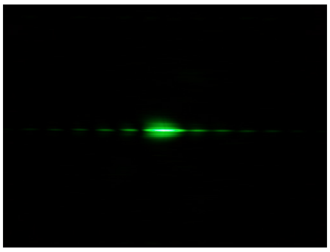
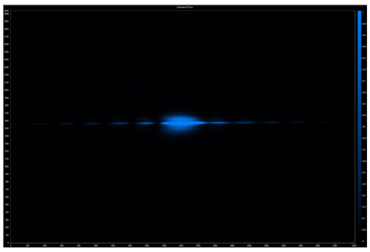
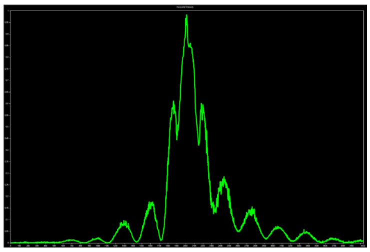
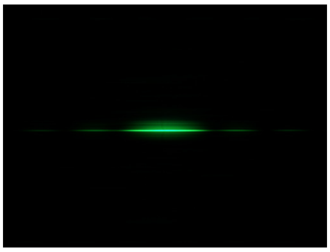
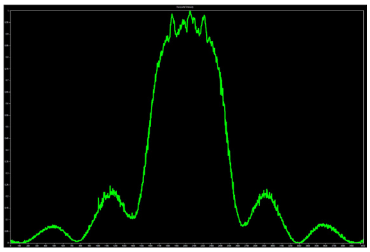
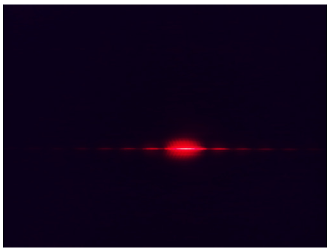
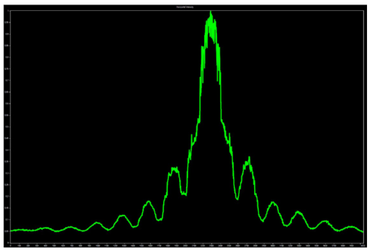
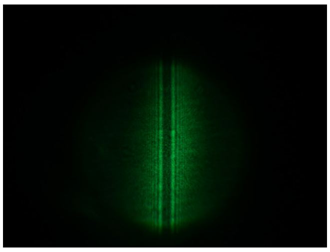
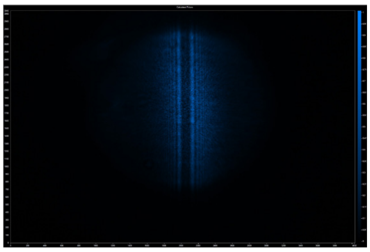
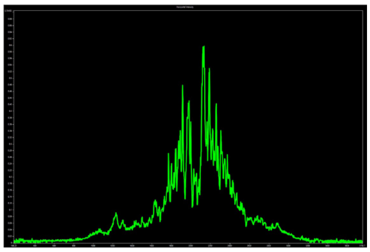
We recall the equation for the intensity distribution behind a slit with a width of b. The intensity distribution is imaged on a screen (or CCD chip) at a distance of L_0. To calculate the intensity distribution on the screen, it makes sense to determine the angle phi using simpler methods. The situation is shown again in the figure and the angle phi can be calculated as

$$\cos\phi = \frac{\Delta x}{L_0}$$

The distance L_0 is the distance between the diffraction sample and the CCD chip of the camera or the observation screen. The value for Δx is determined from the camera image, whereby the full width is 7.564 mm (4032 pixels).

Some examples are shown in the following illustrations. To obtain a high-contrast image, the distances between components are varied, the gain of the CCD camera is optimized or even attenuation filters are used. The images shown are taken with little optimization. They could be better, but they already show a clear analyzable structure.

5.5.1 Examples of some measurements and analyses

Specimen	Real Image	Data Matrix	Analysis
200 µm single slit green Laser			
100 µm single slit green Laser			
50 µm single slit green Laser			
100 µm single slit red Laser			
Wire 50 µm with beam expander			
Gauze 300 mesh with beam expander