LOS – 1

LASER OPTICS SET

Contents

1 Introduction

By using our new Laser Optics Set LOS-1 (Fig. 1) you have an opportunity to improve the educational process of high school physics. The coherent light source – the laser – provides you with innovative and “hands on” way of teaching about wave optics, that is a favourable alternative to more conventional and theoretical methods. The Laser Optics Set LOS-1 enables the demonstration of optical phenomena as ray tracing, reflection of light, polarisation of light, as well as both the diffraction and interference of light. The Laser Optical Set LOS-1 also contains a Fresnel type hologram.

To follow are some experiments designed for demonstration by the Laser Optics Set. It is up to the teacher whether he or she wishes to elaborate on the basic experiments.

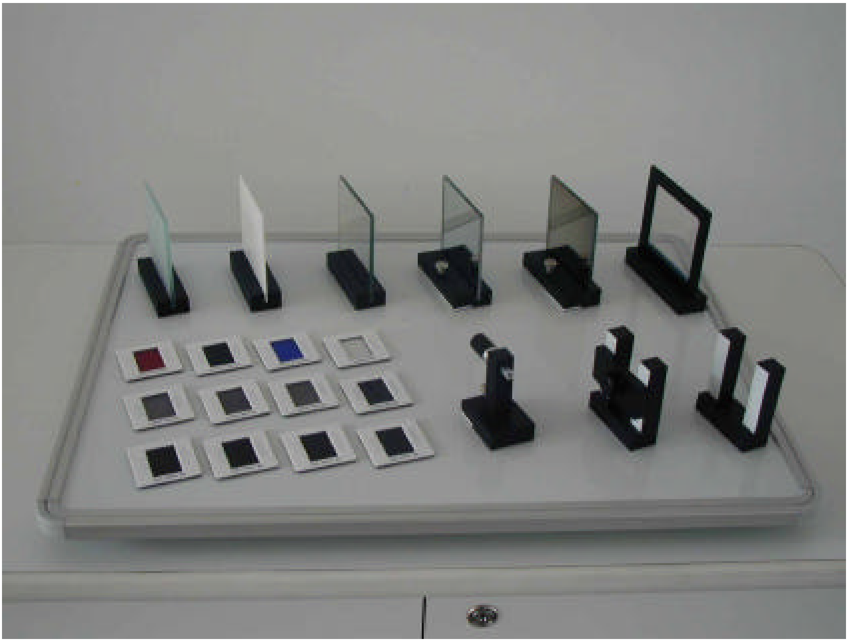

Figure 1

The components of the set are contained in a briefcase padded with foam to prevent damage to the optomechanical elements. A magnetic table is included, which in addition to its main function of element fixation, can be used as a whiteboard. It has four magnetic rubber pads on its base for stability.

Contents of Laser Optics Set LOS-1

- 1 laser diode 635 nm of 1 mW output power (laser class 2)
  Attention: Avoid direct laser beam exposure of the eye
- 1 converging lens
- 2 mirrors
- 1 semitransparent mirror
- 1 ground screen
- 1 screen
- set of colour filters (F1 red , F2 green , F3 blue)
- 1 polarising filter
- set of circular diffraction apertures (D1, D2)
- set of square diffraction apertures (D3, D4)
- set of diffraction linear gratings (G1, G2, G3)
- 1 diffraction cross grating (G4)
- 1 hologram
- 1 glass plate for interference demonstration
- set of 9 holders
- 4 rubber pads
- battery box (2x1.5V AA)
  All optomechanical elements use magnetic fixation.

2 Light interference

Interference is a phenomenon by which two or more light beams interact and due to the mutual phase shift the final intensity is not simply the sum of intensities of the individual light beams. Early in the eighteenth century two theories attempted to explain light origin. The first one was Huygens' Wave Theory and the second was Newton's Corpuscular Theory. In 1801 the English doctor and physicist T.YOUNG discovered the effect of interference on light radiation and explained it using the Wave Theory. He clarified the colour scheme of thin layers in terms of interference. The French physicist J.A.FRESNEL applied the principle of Wave Theory to explain bending and interference phenomena.

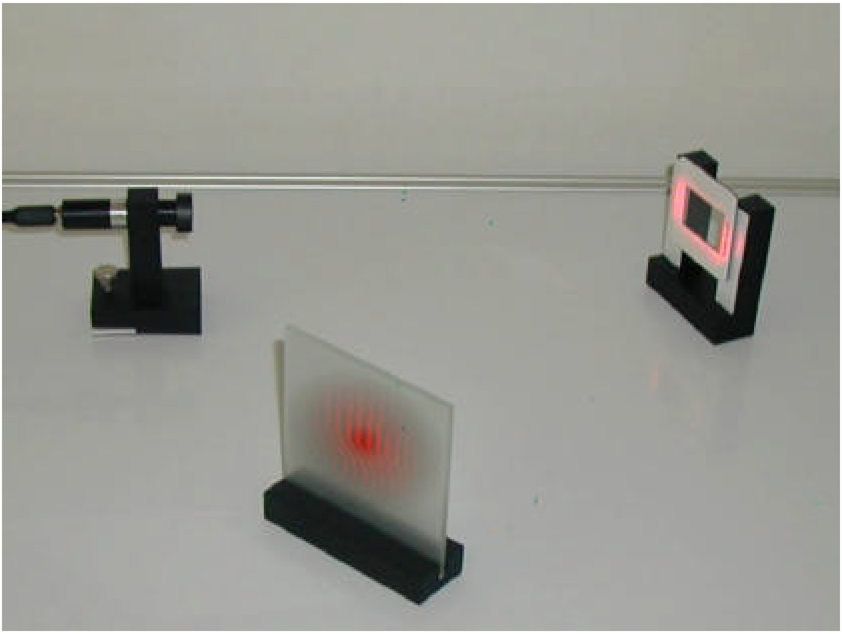

Figure 2

2.1 Light interference on a thin glass plate

Objective

Observation and explanation of interference pattern.

Equipment

Laser (635 nm), ground screen, glass plate, frame holder, lens.

Procedure (Figure 3)

1. Place the laser without the lens in the corner of magnetic table, the laser beam should be parallel to the longer side of the table.
2. Place the holder with the glass plate in the other corner of the table. The laser beam spot should be visible on the plate. The vertical position of the beam spot can be adjusted by turning the nut in the laser holder.
3. Position the ground screen in the corner diagonal to the glass plate (Figure 3).
4. Rotate the glass plate holder until the beam spot is in the centre of the ground screen.
5. Place the lens holder with lens directly in front of laser or place the lens without holder in contact with the laser to produce a diverging beam. The diameter of the beam should not be greater then the diameter of the glass plate, to maximise light utilisation.
6. Observe the interference pattern on the ground screen. Adjust its position to see the best interference pattern.

Question

Interference is an effect caused by the presence of at least two waves. Which two waves interfere in our case?

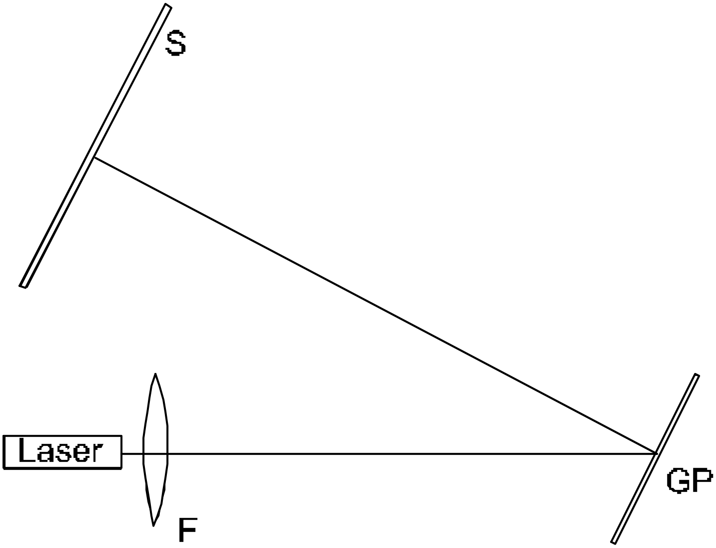

Figure 3: The experimental set-up scheme for demonstration of interference of light waves reflected from a thin glass plate: F–lens, GP–glass plate, S–ground screen.

2.2 Michelson's interferometer

Introduction

Interferometers are the devices, by which very fine optical path changes of one of the interfering rays can be measured. We are able to find out imperfections of polished surfaces, different defects of transparent materials, or simply measure a refraction index of some medium using an interferometer.

Michelson's interferometer consists of one semitransparent mirror and two mirrors. Semitransparent mirror SM splits the beam into two ones perpendicular to each other, propagating in the two *arms* of the interferometer. These beams are reflected by the mirrors M_1 and M_2. Then they go back through the arms and after transmission of the semitransparent mirror they join again. The beams are carrying an information about the length of the arms. The position of the interference fringes depends on the difference of the mirrors distances from the semitransparent mirror SM.

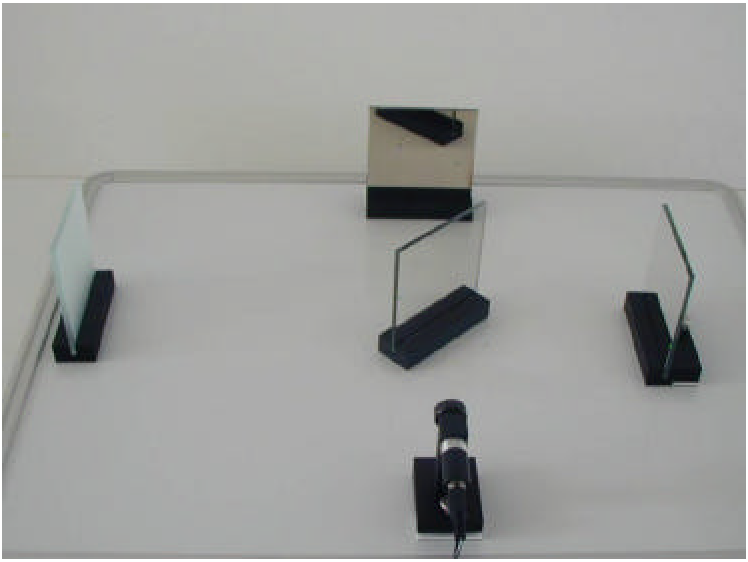

Figure 4: Michelson's interferometer.

Objective

To observe an interference pattern using Michelson's interferometer.

Equipment

Laser (635 nm), ground screen, 2 mirrors, 1 semi-transparent mirror, lens.

Procedure

1. Position the laser half way along the longer side of the magnetic table (Figure 4) and adjust the laser beam **parallel** to ground plate (see Notes).
2. Position mirror M_2 on the opposite side of the table (Figure 4), ensuring that the side without the screw is facing the laser. Direct the beam back to the laser by adjusting the screws on the laser holder and the mirror holder.

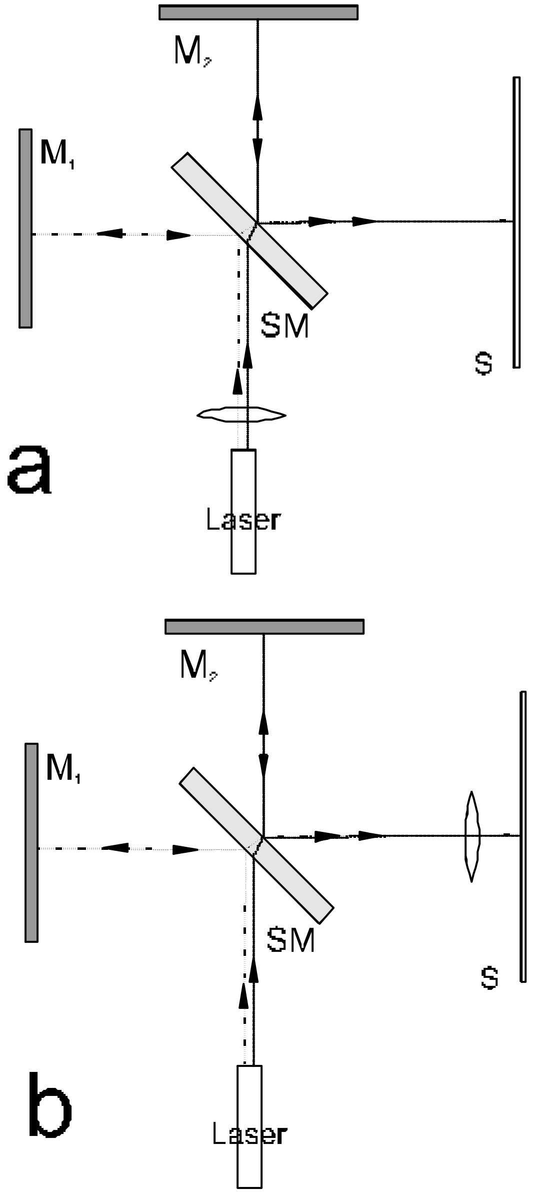

Figure 5: The scheme of Michelson’s interferometer. M_1, M_2 – mirrors, SM – semitransparent mirror, S – ground screen, F – lens.

3. Position the semi-transparent mirror between the laser and mirror M_2 as shown in Figure 5. The angle between the semi-transparent mirror plane and the axis of the laser beam should be 45°. Correct positioning is vital.
4. Position the ground screen as shown in Figure 5, on the shorter side of the table. The beam spot should appear in the centre of the screen
5. Place mirror M_1 opposite the ground screen on the other side of the table.
6. Merge the spots on the screen by moving mirror M_1 slightly and adjusting the screw on the mirror holder and place the spots on the same **height** as the laser source (see Notes).
7. Position the lens between the semi-transparent mirror and the laser. This causes a typical interference pattern to appear.
8. If the lens were between the ground screen and the semi-transparent mirror (Figure 5b), parallel interference fringes would be observed. This is when interference between two spherical waves occurs, when they are propagated through a wide angle or the axes of their beams are parallel, but not overlaid.

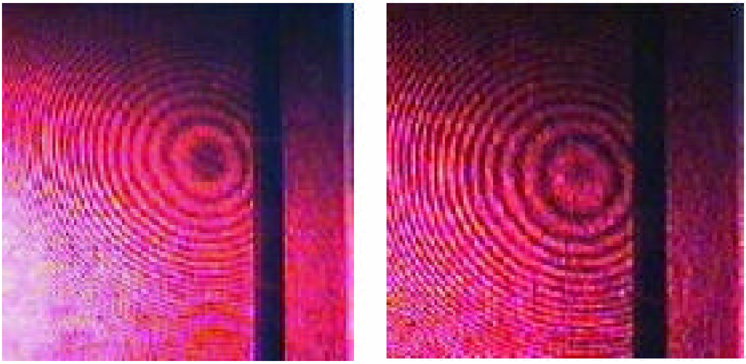

Figure 6: The interference pattern of two spherical waves when the axes of the beams are overlaid or form a small angle.

Notes

- Before the beginning of the experiment clean the lens, so that no parasite interference on dust particles attached to lens surface occur. You can easy identify such parasite interference as number of concentric circles. An interference of beams coming from only one of mirrors M_1 or M_2 can occur. This interference is easy to identify as occurring even by covering of one mirror M_1 or M_2.

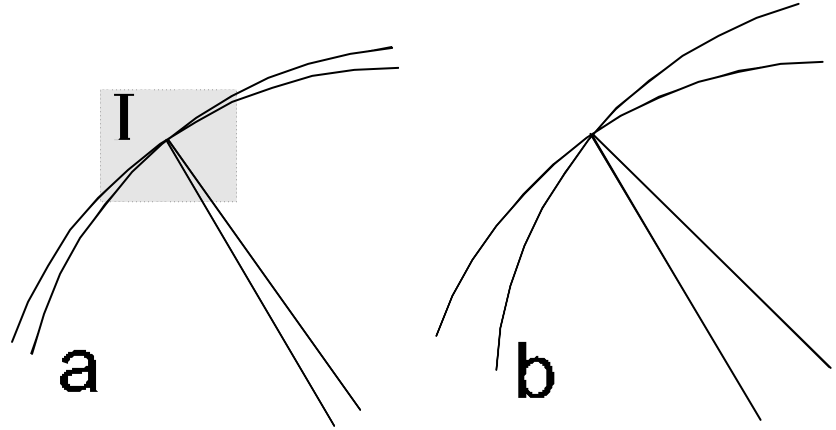

Figure 7: Interference of two spherical waves.

- By adjusting of the set according to Figure 5a is very important that the interfering spherical waves are containing only small angle (see Figure 7a), than we can observe the interference in I area. If the spherical waves contain to big angle (Figure 7b) the interference can not be observed. Therefore it is very important that the wave axis should contain small angel horizontally and vertically and they should intersect nearly to the middle of image screen. Therefore it is important to adjust the laser beam parallel to ground plate and try to keep it parallel after reflection from mirrors M_1 and M_2. Than its possible to observe the typical interference image of Michelson interferometer, which is very easy to identify as pulsing and very sensitive. If the interference image does not vanish after covering of one mirror it is surely the parasite interference.
- Before the placing of mirrors justify the laser so that the beam will be parallel to ground plate. After placing and adjusting of mirrors observe two images of laser beam on the screen. Means adjusting the mirrors and laser place this two images in the same height as the laser source and on the same place on the screen. This way it is secured that the beam axis will be parallel to ground plate and will intersect the image screen. It is better to carry out this adjustment without the lens placed after the laser

- It is very helpful to adjust the mirrors by positioning the laser very close to semitransparent mirror. The mirror images should be nearly of the same shape and position. After finding the interference image we can move the laser source free, without affecting the success of the interference.
- In accordance to Michelson interferometer high sensibility is it very important to place the base plate very stable resistant to shake disruption and touch the whole set by adjusting very carefully.
- If there is no interference image on the screen, remove the lens and ensure that the interfering beams are parallel to ground plate and are hitting the screen at the same place. If that's correct and there is no interference image anyway, it may be that the optical ways are of so close length that interference can not be observed. In that case move one of the mirrors on the optical axis back or forward about 1 mm.

Questions

Can you explain the origin of the "pulsing eye"?

Try to heat locally the air on different places in the line of the interfering beams and observe the interference image. Try to explain the observation.

After interference image is acquired try to change the angle of the laser beam means the adjusting screw and observe how will change the position and shape of the interference image. By changing the beams´ angle be very careful and try to avoid any disruptive shakes.

3 Light diffraction

Light diffraction is a property of “wave motion” – in which waves spread and bend as they pass through small openings or around barriers. The principle of light diffraction can be explained by Huygens’ Theory. He proposed that when a wave of light passes through an aperture or around a barrier every point of it acts like a secondary wave source. These waves then travel different paths and subsequently interfere with each other. A typical *diffraction pattern* can be obtained by inserting a screen into the interference field.

3.1 Light diffraction on a square and a circle aperture

Introduction

The diffraction pattern depends on the shape of the aperture or barrier (Figure 8). If light is diffracted through a circular aperture, the resulting pattern appears as a series of concentric circles, whereas if it is diffracted through a square aperture the resulting pattern is a series of stripes which form a cross shape.

Objective

To observe light diffraction through apertures of different shapes.

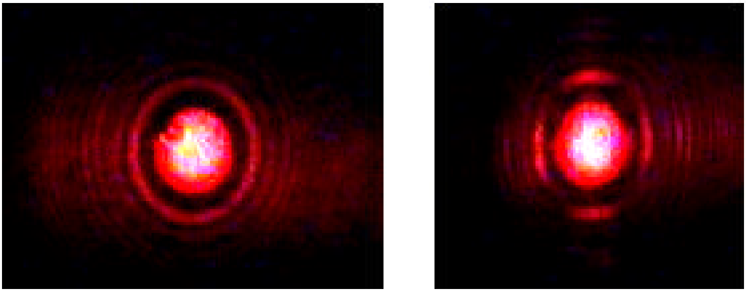

Figure 8: Patterns produced when light is diffracted through circular and square apertures.

Equipment

Laser (635 nm), square and circular apertures, frame holder, ground screen.

Procedure (Figure 9)

1. Attach the square or circular aperture slide to the magnetic stand.
2. Position the stand between the laser and the screen. The distance between the aperture and the screen should be at least 50 cm.
3. Observe the diffraction patterns by using different apertures.
4. The equation for diffraction through a circular aperture

   $$\sin j = k\frac{l}{D}$$

   where j – diffraction angle, k – diffraction order (0, 1, 2, …), l – wavelength of light, D – diameter of aperture.

Questions

1. What differences can you observe using two different circular apertures?
2. How is the diffraction pattern different when you move the screen further away from the square aperture?

3.2 Light diffraction on a grating

Introduction

An optical grating is a device which consists of many parallel slits which have been made close together. The distance between two neighbouring slits is called the *grating constant.* Any spatially periodical structure which can influence the amplitude or phase of light passing through it is referred to as an optical grating.

Objective

To observe the diffraction pattern of light passed through a grating.

Equipment

Laser (635 nm), linear gratings of different grating constants (G1, G2, G3), cross grating (G4), magnetic stand, ground screen.

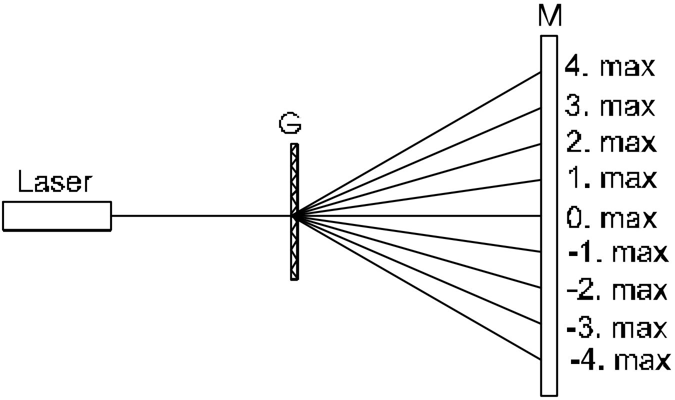

Figure 9: The diffraction set up scheme. G – diffraction medium (square aperture, circle aperture, grating), M – ground screen.

Procedure

1. Position the laser and the ground screen opposite and as far as possible from each other on the magnetic table.
2. Position the grating between the laser and the screen. The distance between grating and the screen should be at least 50 cm.
3. Observe the diffraction pattern. It consists of so-called higher order diffraction maxima (Figure 10). The zero-order maximum is identical to one without grating.
   Similar to the equation for apertures, the equation for diffraction maxima can be written thus:
   $$\sin j = m\frac{l}{d}$$
   where j – diffraction angle, m – diffraction order (0, 1, 2, …), l – wavelength of light, d – grating constant.
4. Observe the diffraction on gratings of different types (G1, G2, G3, G4).

5. Try to insert two gratings into the set-up at once, one behind the other. Observe the diffraction pattern.

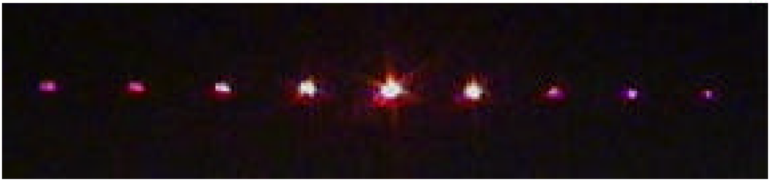

Figure 10: The diffraction pattern of a linear grating.

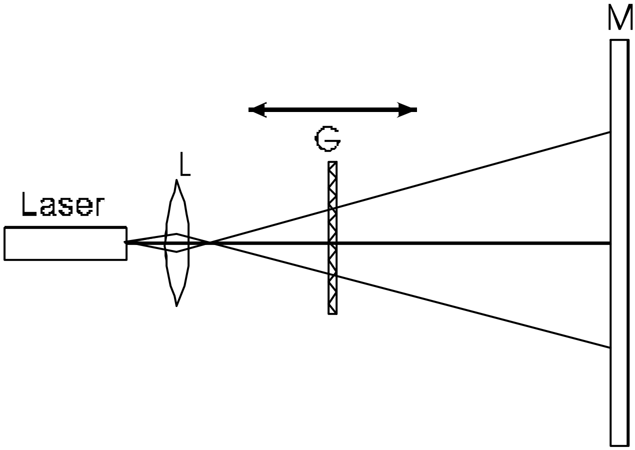

Figure 11: The diffraction set up scheme. G – grating, L – lens, M – ground screen.

Questions

1. What can be said about the mutual distances of maxima using gratings of different grating constants (periods)?
2. How does the diffraction pattern change using gratings of different types or their combinations?

Other tasks

1. Observe diffraction on a human hair. Attach the hair to the stand using magnetic needles.
2. Attach a razor to the stand and observe the diffraction pattern on an edge.
3. By positioning two razors close together, make your own slit. Observe light diffraction on the slit.
4. Cover the part of the laser beam on grating and observe the change of diffraction image. Try to explain.
5. Approximately 5 cm behind the laser place the lens (Figure 11). Place the grating after the lens so that a major part of it is covered by the beam. Move the grating closer to the lens and observe the changes of the diffraction image.
6. Do the same task as in case 5. with exchanged the lens and grating and moving the lens.

Attention

Take sensible precautions when using razors to avoid injury.

Avoid direct eye contact with the laser. Light scattered through the ground screen is not dangerous.

4 Holography

4.1 Hologram recording

Holograms are recorded on special photographic material. The interference field of both the *object* and the *reference* waves is recorded. The object wave is reflected by an object and the reference wave is usually a planar one. The object wave carries information about the recorded object. If this wave were recorded without any reference wave, only amplitude record, normal photography would be obtained. When a reference wave is present a phase record occurs. Such a record is able to save information about the spatial relations of the object. The diffraction field of the object and the reference wave is recorded and photo-chemically processed. An optical grating is obtained on which light can diffract.

4.2 Hologram reconstruction

Introduction

If a light wave passes through a hologram, the situation will be similar to that observed during recording. The set-up for hologram recording is the same as the one for reconstruction (Figure 12) but the eye should not be taken into account and the glasses should be real (contrary to the reconstruction where only an image of the glasses is observed). The light emitted from the laser is a reference wave and the wave reflected by the glasses is an object wave.

During reconstruction light from the laser passes through the hologram (*hologram grating*) and diffracts. Diffraction results in a reconstruction of the situation during recording. The glasses appear only at the 1st diffraction maximum. Reconstruction is achieved through a light diffraction.

Objective

To observe a hologram reconstruction.

Equipment

Laser (635 nm), lens, hologram.

Procedure

1. Arrange the components on the optical table as shown in Figure 12.
2. The larger the area of illuminated hologram, the more visible is the reconstructed image. The lens should be in direct contact with the laser and the hologram should be positioned as far as possible from the laser and turned with red spot to laser.

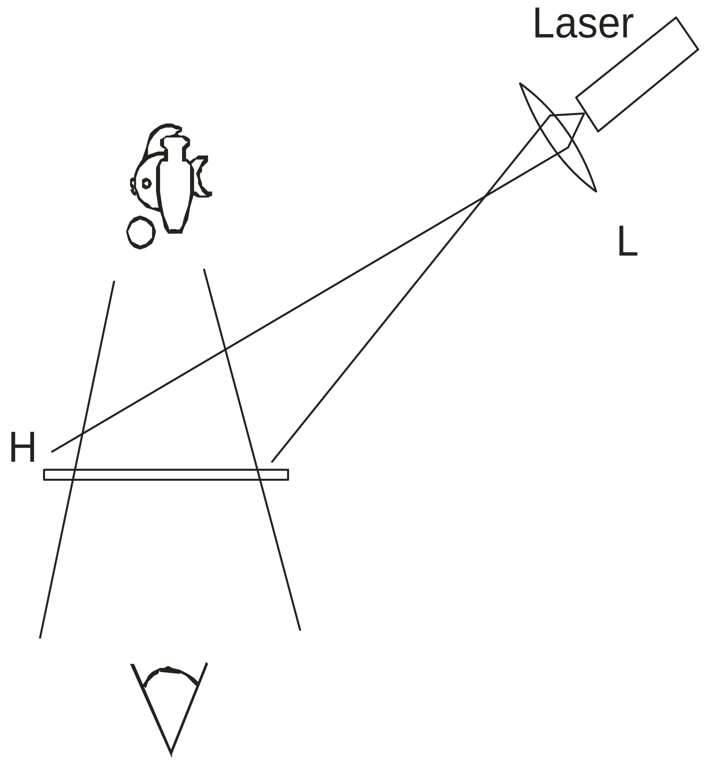

Figure 12: Set-up for hologram reconstruction. L – laser, S – lens, H – hologram.

3. Observe the hologram at an angle of approximately 30 °. Rotate the hologram plate slowly until a holographic image (Figure 13) appears[1]. If you cannot locate the image, try turning the hologram 180 °, or move your head slightly (observation at 30 ° can be achieved from two different positions).

Question

What happens if you move your head to the right and left when observing a hologram?

Figure 13: Hologram photography.

Attention

Be especially careful when attempting to view the image. Do not attempt to observe the image through the 0th diffraction maximum!

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[1] The picture in the Figure 13 is only an example. Your set may contain an image of three glasses or a glass fish.

5 Polarisation of light

Polarisation is a property of transverse waves. The existence of light polarisation demonstrates that light waves are also transverse. The majority of light sources emit non-polarised light. Partially linearly polarised light is emitted from the laser in your set. Its electric field strength vector **E** of light is parallel to the plane of the optical table.

A *polarizer* is an optical element which is able to select one direction of polarisation. When polarised light impinges a polarizer, it is possible to prevent light from travelling beyond it by rotating the polarizer (the direction of the light polarisation and the direction of the polarizer axis are perpendicular). By using a polarizer we can analyse different kinds of light polarisation. Used in this way the polarizer is known as an *analyser*.

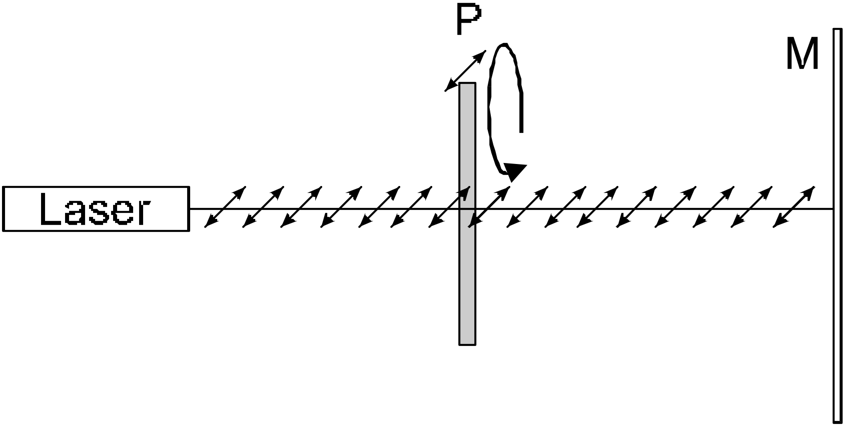

Figure 14: Demonstration of the polarizing properties of light. P – polarizer, M – ground screen.

Objective

To observe light polarisation.

Equipment

Laser (635 nm, linearly polarised), ground screen, polarizing filter.

Procedure

1. Set up the experiment as shown in Figure 4.
2. Rotate the polarizer around the optical axis.
3. Observe the changes of intensity of the laser beam spot on the screen.

Caution

No light is visible on the screen due to the perpendicular direction of the polarizer axis and the **E** vector of laser light. However this does not mean that your eyes are protected from the laser beam. Direct eye contact with the laser beam can permanently damage your sight.

6 Absorption of light

Introduction

Light absorption in an optical homogeneous environment can be explained by Bouger's Law. This law describes the effect of the thickness of absorbing medium on the relative decrease of light flow. This is shown by the following equation:

$$f = f_0 e^{-kx}$$

where f_0 is light flow at the entrance of the absorbing medium and f is light flow after transition through the medium with thickness x.

Objective

To observe light absorption with colour filters.

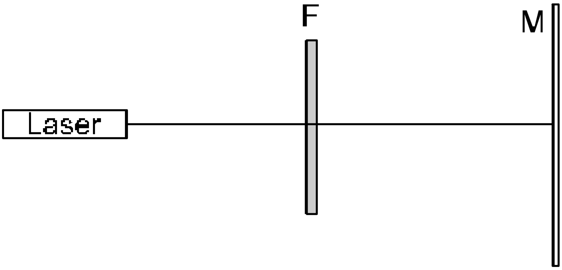

Figure 15: Demonstration of light absorption with colour filters. L – laser, F – colour filter, M – ground screen.

Equipment

Laser (635 nm), ground screen, colour filters, frame holder.

Procedure

1. Set up the experiment as shown in Figure 15.
2. By using different colour filters observe the changes in beam spot intensity.