

## 1 General Purpose

The main objectives for this experiment are:

- Study the diffraction of light through various apertures.
- Investigate the interference of light from multiple coherent sources, both real and virtual.
- Learn spatial filtering of laser light.
- Learn how to make sensitive optical measurements.

## 2 Introduction

### 2.1 Young's Experiment

Light from coherent sources interferes (see the reference for an explanation of the coherent sources). The coherent sources can be obtained from a single source using Young's double slits (or Young's multiple slits), or by creating virtual sources by diffracting light over a mirror.

Thomas Young first verified this experimentally by producing two coherent light sources by dividing a light wavefront from a single source, as shown in figure(1).

Light intensity  $I$  at point  $P$  of the screen located at the distance  $s$ , depends on the path difference from the sources  $\Delta r = r_2 - r_1$  shown in figure(2),

$$I = I_1 + I_2 + 2 \sqrt{I_1 I_2} \cos \delta, \quad (1)$$

As an exercise derive the above formula where,

$$\delta = \frac{2\pi}{\lambda} \Delta r. \quad (2)$$

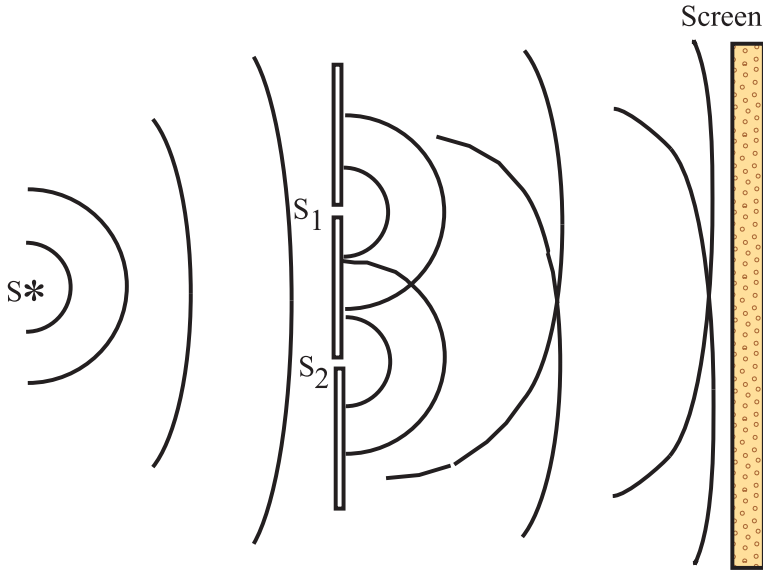


Figure 1: Illustration of Young's experiment.

If the screen is far away from the Young's double slits, the angle  $\theta$  is always small so that:

$$\Delta r = \frac{a}{s}y, \quad (3)$$

since,

$$\begin{aligned} \Delta r &= a\theta, \\ y &= s\theta, \end{aligned}$$

where  $a$  is the separation of the two light sources.

In addition, light intensities from each source separately are approximately equal:

$$I_1 = I_2 = I_0, \quad (4)$$

which leads to:

$$\begin{aligned} I &= 2I_0(1 + \cos\delta), \\ &= 4I_0\cos^2(\delta/2), \end{aligned}$$

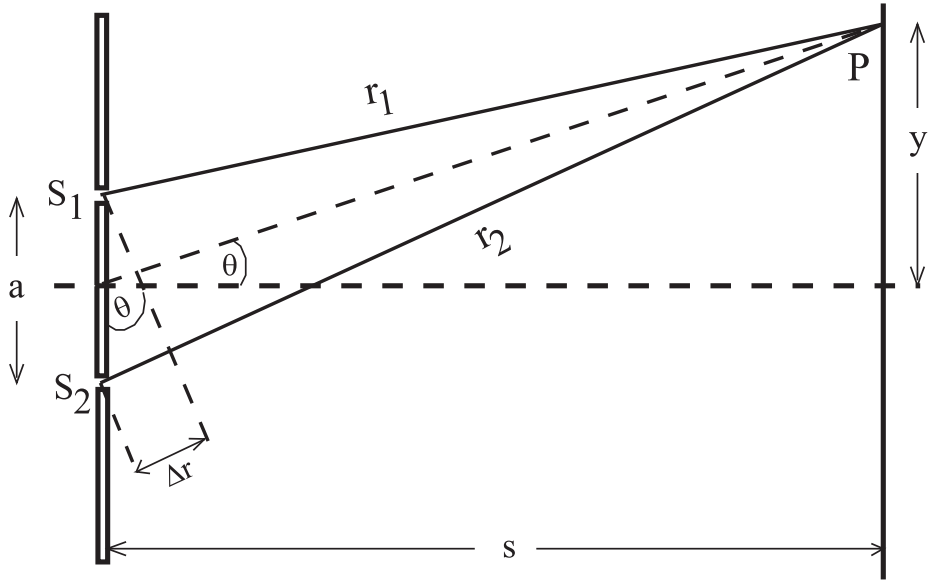


Figure 2: Young's double slits experiment.

$$= 4I_0 \cos^2\left(\frac{\pi a}{\lambda s} y\right). \quad (5)$$

From the above equation show that neighboring maxima (minima) of the light intensity on the screen differ by  $2\pi$  in the phase  $\delta$ :

$$\frac{\Delta\delta}{2} = \pi, \quad (6)$$

so,

$$\Delta y = \frac{\lambda s}{a}. \quad (7)$$

In the original experimental set-up discussed above the interfering sources are real. Variations of the Young's experiment can be achieved using virtual sources. For example, light from a source can be reflected by a plane mirror. The original light source (real source) and its reflection in the mirror (virtual source) interfere ("Lloyd's mirror"), as shown in figure(3).

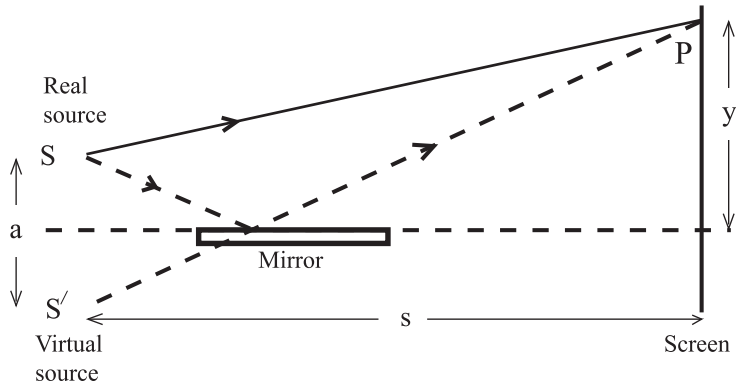


Figure 3: Interference using virtual source.

## 2.2 Spatial Filter And Beam Expander

It is very important to learn how to clean up the light coming directly from a source. The laser is a convenient source of monochromatic light. Laser light has approximately plane wavefronts. Pointlike source of spherical wavefronts can be created by passing laser beam through a lens. The focal point of the lens acts as the source of spherical waves. Figures (4) and (5) show the basic idea of the spatial filter,

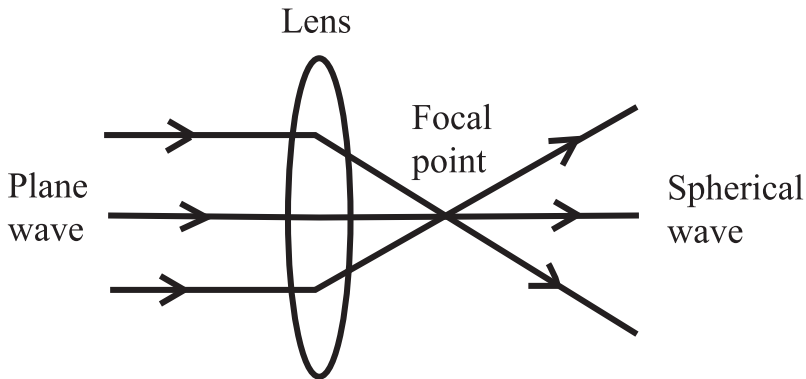


Figure 4: Plane wave coming through a lens.

Not all the laser light is emitted in form of parallel rays (i.e. plane waves). Rays which are not parallel to the optical axis of the lens will not pass through the focal point. To “clean” the laser beam a pinhole of a very small diameter can be placed at the focal point. This system is called a “Spatial filter” and is often used in optical experiments.

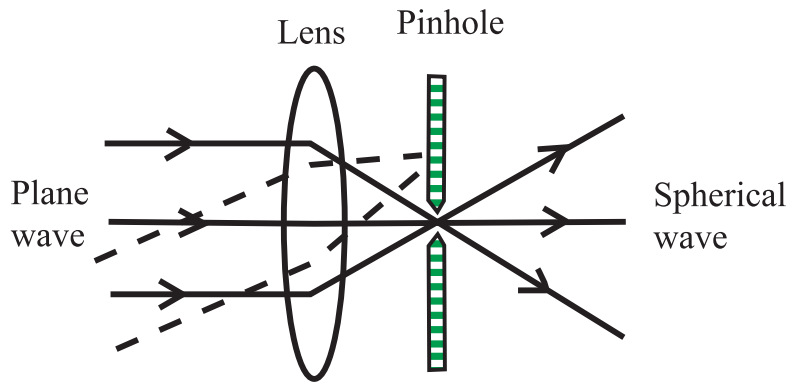


Figure 5: Creation of spherical wave from a plane wave.

The laser beam usually has a very small diameter. To expand the laser beam while preserving the planar wavefronts as shown in figure(6), a system of two lenses with the common focal point can be used (“Beam Expander”),

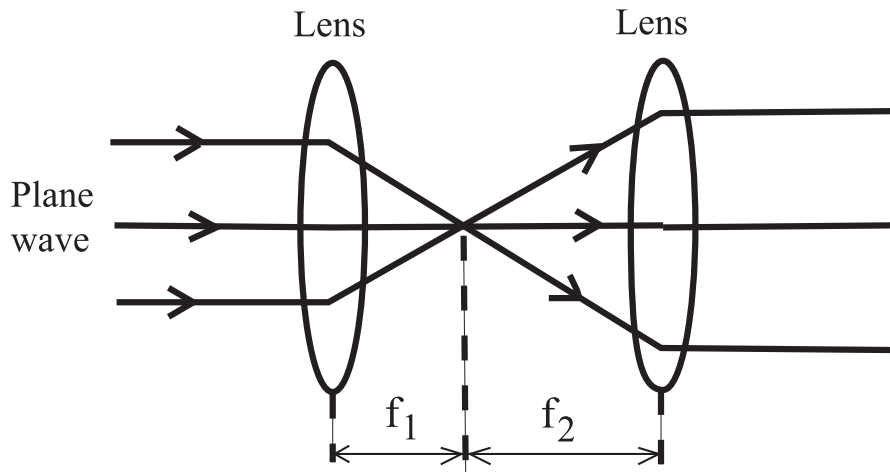


Figure 6: Basic idea of the beam expander.

## 3 Lab Instructions

### 3.1 Instruments To Be Used

Throughout the lab you will use the following instruments,

- A laser which emits green light of wavelength  $\lambda = 543.5$  nm.
- A 10X microscope objective.
- A pinhole of  $25\mu\text{m}$  diameter. Please be careful not to damage the pinhole aperture or allow contaminants near the pinhole – Don't touch the central region of the pinhole assembly!
- Young's double slits with several slit widths and separations.
- Single slits of several widths.
- A lens of 50 mm focal distance.
- A lens of 100 mm focal distance.
- Five component carriers.
- Fresnel's double mirrors.
- Fresnel's biprism.
- A mirror.

### 3.2 Safety

The power output of this HeNe laser is low enough that eye protection is not mandatory for *indirect* viewing. Nonetheless, **never stare directly into the laser beam. Permanent eye damage could result!**

### 3.3 Alignment Of The Laser Beam

Align the laser beam along the optical bench. Use a screen with a scale mounted on a component carrier. Ensure that the laser beam strikes the same position on the screen at the nearest and the farthest distances from the laser. The alignment usually involves several iterations in adjustment of the laser orientation with the screen at the nearest and the farthest position. The laser is mounted on a component carrier. You will have to fix its position for the whole lab and leave it untouched. Any displacement of the laser beam will have a big effect in doing the measurement.

### 3.4 Spatial Filtering

Mount the spatial filter, with no lens or pinhole attached, on a component carrier. Adjust the translation screw on the carrier so that the laser beam goes through the center of the lens holder.

Mount the 10X microscope objective on the filter (a focal length of the objective can be calculated from the magnification power MP:  $f = 160\text{mm}/\text{MP}$ ). Align the position and the orientation of the spatial filter, so that the center of the laser beam coincides with the laser beam position before the filter was installed. Check the beam center at a close and at a distant position of the screen.

Mount the  $25\mu\text{m}$  pinhole in front of the lens. Be careful not to touch the central region of the pinhole assembly! The pinhole diaphragm sticks to the magnetized position control rods. The flat surface of the diaphragm should face the lens. Adjust horizontal and vertical position of the pinhole to see some laser light coming through. Initially, the amount of transmitted light is likely to be very small, so you must work in the dark. It may be quite difficult to find a position of the pinhole in which some light gets through. It is easier to start with the pinhole positioned off the focal plane, otherwise the beam spot is very small and difficult to find.

Then tune the distance between the lens and the diaphragm in small steps, adjusting the vertical and horizontal position of the pinhole after each step. Try to maximize intensity of light which gets through. The maximal intensity is achieved when the pinhole is positioned exactly in the focal point of the lens. The transmitted light should create a bright central spot surrounded by concentric rings coming from diffraction of the laser light on the circular pinhole. The pattern should have a regular circular symmetry.

### 3.5 Diffraction From A Single Hole

The relation between the wavelength  $\lambda$ , the pinhole diameter  $D$  and the angular separation of the central light and the first fringe is given by,

$$\theta = \frac{1.2\lambda}{D}. \quad (8)$$

Use this relationship to measure  $\lambda$ . To do that you have to find a way to measure  $\theta$ . Describe the steps in your lab-book and make a sketch of the pattern you observe on the screen. If  $\lambda$  is not what you expect consult a staff member.

Repeat this process for at least one more separation of the aperture and observation screen.

### 3.6 Beam Expander

Mount a converging lens with  $f = 50$  mm on a component carrier. Adjust the horizontal and vertical position of the lens so the transmitted laser light preserves its original direction. Then, adjust the position of the lens along the bench to obtain the laser beam of a constant transverse size at any point along the bench. Note, this last step is a little bit difficult so try to get it, if you don't get it, don't get upset, just try harder.

### 3.7 Diffraction From A Single Slit

Upon encountering a rectangular slit aperture, coherent waves will diffract producing a pattern of bright and dark bands, as described in Chapter 10 of Hecht. Mount a slide with an array of single slits on a holder and place it on a stand. Using the expanded laser beam, illuminate the slide with the slits and adjust the lateral position of the slide so that the beam is centered on one of the slits. Make a sketch of the pattern you observe in your notebook.

Using the relationship for diffraction from a single slit as described in Hecht, obtain a measurement of  $\lambda$ . To do that you have to find a way to measure the angle. Describe the steps in your lab-book. If  $\lambda$  is not what you expect consult a staff member.

Repeat this process for at least one more separation of the slits and observation screen, and for one different slit width.

### 3.8 Young's Experiment

Two slits separated by a small distance will result in an interference pattern if a coherent source can diffract through each slit. Mount the slide with slit pairs on the holder and illuminate the pair of slits separated by  $a = 0.125$  mm. Observe the interference pattern on the screen positioned at least 2 m away from the slits. You should see parallel interference fringes similar to the diffraction pattern produced by circular pinholes. Measure the separation of two neighboring maxima (or minima),  $\Delta y$ . Count several fringes to estimate  $\Delta y$ . You may use paper with mm grid as a screen. Measure distance  $s$  from the slits to the screen. Calculate the wavelength of the laser light from:

$$\lambda = \frac{a\Delta y}{s}. \quad (9)$$

Estimate accuracy of your measurements of  $\Delta y$  and  $s$ , and propagate these errors to the error on  $\lambda$ . Does your measurement agree with the known wavelength of the laser beam  $\lambda = 543.5$  nm?

Repeat this process for at least two different separations of the aperture and observation screen, two different slit widths, and two different slit spacings.

### 3.9 Lloyd's Mirror

Remove the second lens. The pinhole of the spatial filter will now serve as a source. Use the special mount with a knob for adjusting the height to support the mirror, which should be close to the pinhole. Adjust the vertical position of the mirror so that its surface is approximately parallel to the laser beam (we want to reflect a part of the laser light at a very small angle). Place the screen at distance larger than 2 m.

Now mount the 100 mm focal length lens  $L$  in between the mirror and the screen as shown in Figure(7). The distance between the pinhole and the lens  $L$  should be slightly larger than the focal length of the lens. Adjust position of the lens  $L$  along the bench to see two well focused spots on the screen. These are images of the pinhole ( $I_s$ ) and the pinhole reflected in the mirror ( $I_{s'}$ ).

Adjust the vertical position of the mirror so the images are separated by approximately 1cm. Measure their separation  $a'$ . Measure distance from the pinhole to the lens  $L$  ( $l_1$ ), and from the lens  $L$  to the screen ( $l_2$ ).

The separation  $a$  between the actual source  $S$  (pinhole) and the virtual source  $S'$  (pinhole reflection in the mirror) can be calculated using the following relationship:

$$a = \frac{l_1}{l_2} a'. \quad (10)$$

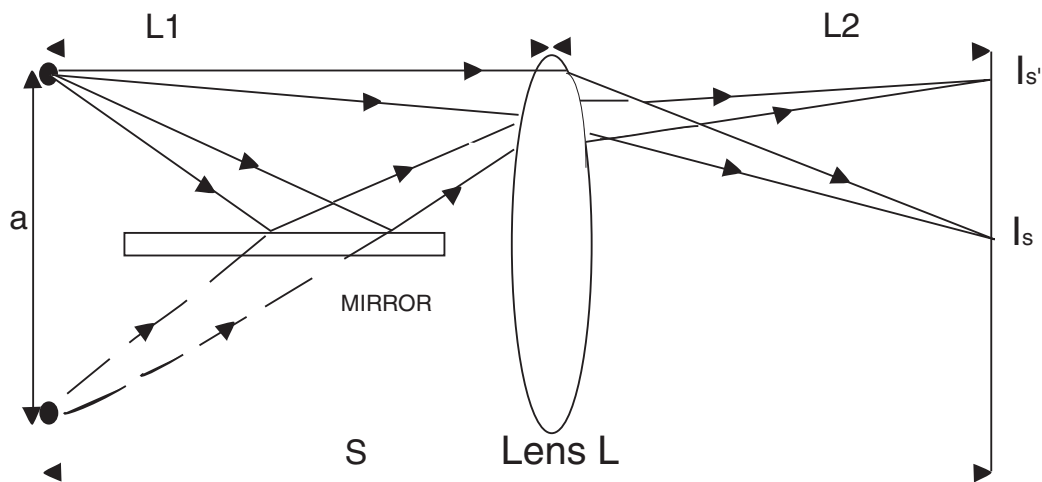


Figure 7: Illustration of Lloyd's mirror experiment.

Remove the lens  $L$  and observe interference fringes in the region where cones of light from  $S$  and  $S'$  overlap. Note that even when the two beams (direct and reflected) do not overlap you may observe some interference fringes which are produced, however, by diffraction at the edge of the mirror rather than by the interference of the two sources. Look for distinct fringes in the overlap region of the two cones of light.

Measure separation of the fringes  $\Delta y$  and distance from the pinhole to the screen  $s$ . Using Young's formula calculate  $\lambda$  and estimate the error on it and then compare your result to the true value.

Repeat this process for a different height of the mirror, thus producing a different separation between the virtual and real sources.

### 3.10 Fresnel's Double Mirror

Mount the Fresnel's double mirror on a component carrier with horizontal and vertical translation screws. Position the mirror in front of the spatial

filter. Try to understand the function of each adjustment screw on the mirror holder. Identify the movable shield perpendicular to the mirrors. Make the surfaces of the two mirrors approximately parallel. With the mirrors directed at a large angle to the beam, position the mirror holder so that the beam is incident at the center of the mirror division, splitting the beam intensity in half between the mirrors. Now, rotate the holder so that an angle between the mirrors is rather small (beam should slide across the surface of both mirrors). You should observe on the screen, which may need to be positioned off the bench axis, two reflected cones of light. The undeflected light may also be seen. You may use the movable shield to suppress undeflected light. See how you can use adjustment screws attached to the mirrors to control the direction of the deflected light. Interference fringes should be observed when edges of the two deflected cones of light overlap. Measure  $\lambda$  of the laser light by a similar method as already described for the Lloyd's mirror.

### 3.11 Fresnel's Biprism (time permitting)

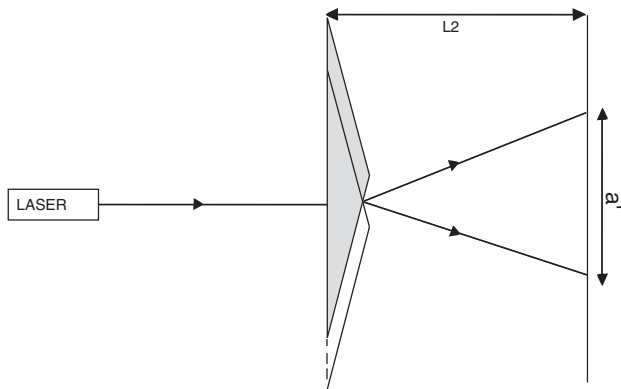


Figure 8: Illustration of Fresnel's biprism experiment.

Mount the Fresnel's biprism in front of the spatial filter, see Figure(8). Observe interference fringes in region where the two refracted light cones overlap. The screen should be at least 2 m away. Try to change the fringe separation  $\Delta y$  by moving the biprism along the bench. For a selected position measure  $\Delta y$  and the distance between the pinhole and the biprism  $l_1$  and the biprism and the screen  $l_2$  ( $s = l_1 + l_2$ ).

Now remove the spatial filter and project the direct laser beam on the biprism. Since it takes a lot of work to reinstall the spatial filter, remove it

only when you are really ready. Move the biprism in the plane perpendicular to the beam so that the laser beam passes through only one half of the biprism, as shown in Figure(9). Mark the position of the deflected laser beam on the screen. Now move the biprism again so the laser beam passes through the other half of the biprism. Mark the position of the deflected beam and measure the separation from the previous position call it  $a'$ .

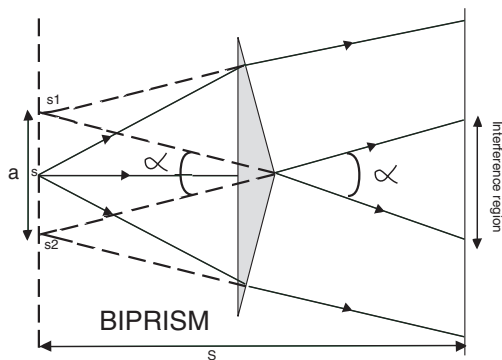


Figure 9: Fresnel's biprism

From this measurement  $\beta = a'/l_2$ . Since  $\beta = a/l_1$  we can find the separation of the virtual sources  $a$ , and then using Young's formula, find  $\lambda$ ? Estimate error on  $\lambda$ ?

## References

- [1] *Optics*. E. Hecht, A. Zajac, (available in room 377).
- [2] *Fundamentals Of Physics, Fourth edition*. D. Halliday, R. Resnick, J. Walker (It is available in the reserve section of the Physics Library).