Experiment 7

Diffraction

Equipment Needed

- Incandescent Light Source (OS-9102)
- Optics Bench (OS-9103)
- Component Carriers (3) (OS-9107)
- Photometer Apertures (OS-9116)
- Diffuser (OS-9120)
- Diffraction Slits (OS-9165A,B,C,D)
- Photometer with Optic Probe
- Linear Translator
- 0.5 mW Laser
- Laser Alignment Bench (OS-9172)
- 48 mm F.L. Lens (OS-9133)
- Viewing Screen with Metric Scale (OS-9138)

Introduction

Around 1800, the English scientist Thomas Young designed and performed an experiment which produced seemingly unexplainable phenomena. At least, it was unexplainable in terms of the early "corpuscular" theory of light. Young observed the image of light passing through first one slit, then two slits closely spaced and parallel to one another. He used filtered light from a mercury arc to insure that he had nearly monochromatic light. The first slit insured that light striking the double slit further on had a definite phase relationship among various points on the wave front (*i.e. coherence*). The image that Young observed was a series of light and dark areas which did not represent a plain geometrical image of double slits. Furthermore, a point on the screen which was illuminated when one of the double slits was covered became dark when both slits were uncovered. A "corpuscular" theory (in which light is comprised of a series of particles) cannot adequately explain this phenomenon.[1]

We can re-perform Young's experiment and, in fact, eliminate the first slit. If we place the double slits far enough from the light source, the first slit becomes unnecessary. This shows that there is a definite phase relationship between points on the wave front which pass through the double slits. In other words, in a small angle, light from an incandescent source is spatially coherent.

PROCEDURE:

A. Position the light source at the left end of the optical bench.

B. Attach the diffuser, double-slits and photometer apertures to three separate component carriers.

C. Position the double-slits about 20 cm from the light source. Place the photometer apertures between the light source and double slits.

D. Pick a sufficiently large single slit on the photometer aperture slide and adjust the position of this slit until one set of double slits is fully illuminated.

E. Position the diffuser behind the double slits and adjust its distance from the slits until there is a sharp geometrical image of the two slits. (View the image from the side of the diffuser which faces away from the light source.)

F. Move the diffuser slowly away from the slits until the sharp geometrical image becomes an interference pattern with several maxima and minima.

G. Adjust the single slit (*i.e.* one of the photometer apertures) until only one of the double slits is illuminated. Observe the image (it is not a clear image, but rather a diffraction pattern).

H. Now illuminate both slits and observe the image. Notice that some points previously illuminated are now dark.

I. Move the double slits and diffuser to the far right of the bench and observe that the single slit is no longer necessary. (However, you still need some sort of edge to cover one of the double slits in order to examine the two different patterns. It is convenient to attach the aperture mask to the same component carrier as the double slits. Adjust the mask's position to allow one or two slits to be illuminated.

[1] Not, that is, until the advent of *quantum mechanics*, in which the distinction between waves and particles became forever blurred.

J. Attach the photometer's fiber optic probe to the linear translator and use the translator to scan the images. Place a small aperture such as the light source apertures in front of the probe on the rear surface of the analyzer holder. Adjust the aperture so that light incident on it enters the probe. Using the aperture minimizes effects due to ambient light. Plot intensity versus position for both one slit uncovered and two slits uncovered.

K. Measure the intensity of the bright middle band ($I_{\max}$) and then measure the intensity at the middle of the first shaded bands on either side ($I_{\min}$). Calculate the Michelson visibility coefficient (V) from:

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \tag{1}$$

This coefficient gives a measure of the coherence of the incident light with $V = 1.0$ indicating perfect coherence.

7.1 The Laser

The laser is based on the phenomenon of stimulated emission. If an electron of a given atom is in an excited state and if a photon of proper frequency interacts with this electron, the electron is triggered into de-exciting itself by emitting a photon. Moreover, the original photon continues on its way, unchanged. This process continues in a chain reaction causing a "photon cascade". When the cascade is sufficiently intense, it bursts through the partially reflecting mirrors of the laser cavity. This burst perfectly coherent since the photons are all in phase. Since the photons have the same frequency, the light is essentially monochromatic.

Note: Due to the design of the lasing cavity, the laser beam is collimated and therefore there is little loss of energy flux due to divergence of the light beam. The 0.5 mW He-Ne gas laser produces about 1/4th of the energy flux of the sun. Although this energy level seems to be below that which causes permanent eye damage, in order to insure safety, never look directly into the laser beam or its mirror reflection.

7.2 Diffraction of Laser Light by Slits

When light passes near the edge of an opaque object and then onto a screen, there appears to be some illumination in the area of the geometrical shadow. In other words, light fails to travel in straight lines when passing sharp edges. This phenomenon is called diffraction and occurs because of the wave nature of light.

There are basically two categories of diffraction effects. The first is Fraunhofer diffraction, which refers to diffraction produced when both the light source and screen are an infinite distance from the given obstacle. Fresnel diffraction is the second type and refers to diffraction produced when either the source or screen or both are at finite distances from the obstacle. We can observe Fraunhofer diffraction experimentally by using a collimated light source and placing the viewing screen at the focal plane of a double convex lens located behind the obstacle.

Since light does not travel in straight lines near a sharp lines, there are many different path lengths from the obstacle to the screen. If there is sufficient difference in path length, two waves reaching the same point may be 180° out of phase, resulting in destructive interference. On the other hand, constructive interference may also occur. The complete explanation of patterns observed in Young's experiment depends on both diffraction and interference effects.

When we use the incandescent source in studying diffraction, we get an interference pattern, but since the interference patterns depend on the wavelength of the light and since white light contains light of various wavelengths, the patterns are not sharp. The coherence and monochromaticity of laser light makes it ideal for this experiment.

7.2.1 Laser Alignment

Position the laser at the left end of the bench and align the beam. You can adjust the laser so that the beam is parallel to the optical bench as follows:

A. Place a piece of masking tape or paper over the square hold on the front of a component carrier. Make a small dot on the tape/paper in the center of the square hole (1 inch from the top of the component shelf and 1.5 inches from the edge of the component holder).

B. Place the laser on the alignment bench and make sure it is reasonably parallel with the bench.

C. Place the component holder on the optical bench about 10 cm from the laser aperture. Make sure that the component carrier is flush against the alignment rail of the bench. The dot on the paper now marks the optical axis of the bench.

D. Turn on the laser, and move the aperture end of the laser sideways, as needed, so that the laser beam falls on the dot.

E. Move the component holder about 90 cm away from the laser aperture. Again, be sure the edge of the component holder is flush against the alignment rail of the bench.

F. Without moving the aperture end of the laser, move the rear end of the laser to recenter the laser beam on the spot. You may also need to adjust the leveling screws on the laser alignment bench in order to center the beam vertically on the dot.

G. Repeat items 3 through 6 until the beam is centered on the dot for both positions of the component holder.

7.2.2 Diffraction and Interference of Monochromatic Light

A. Attach the slide of single slits on a component carrier and position the assembly midway down the bench.

B. Attach the viewing screen to a component carrier and position it at the right end of the bench.

C. Adjust the slit position until the laser beam is incident on the full width of the slit.

D. Observe the diffraction pattern on the screen. Adjust the screen position if necessary to obtain image clarity. This is an example of Fresnel diffraction.

E. With the slits attached to the side of the component carrier facing the laser, attach the 48 mm F.L. lens to the other side.

F. Move the screen to the focal plane of the lens (*i.e.* 48 mm from the center of the lens) and observe the diffraction pattern. This is an example of Fraunhofer diffraction.

G. Now replace the screen with the linear translator (with fiber optic probe attached). Check that the unobstructed laser beam is at the proper level to be incident on the photometer probe (adjust if necessary). With the photometer shutter closed, adjust the translator so that the beam strikes the center of the probe. Now place the photometer aperture slide on the rear surface of the translator's analyzer holder so that the 0.1 mm slit crosses the center of the beam. With this setup, only light incident on the small slit will be read by the photometer.

H. Form another diffraction pattern and slowly scan the pattern with the translator. Plot intensity versus position. Verify that the relative intensity falls off as:

$$I \propto \left(\frac{\sin\theta}{\theta}\right)^2 \tag{2}$$

Note: If the laser has not warmed up for at least 1.5 hours, there may be fluctuations in the beam intensity due to the expanding laser tube.

I. Form the diffraction pattern of multiple slits and slits of varying sizes and separation. If the images are too small, magnify them with a series of lenses.

J. Spread the beam of the laser (see Fig. 7.2.2) and illuminate the special patterns of slide OS-9125. Observe the diffraction pattern (Fraunhofer and Fresnel). Attempt to deduce the dimensions of the original aperture arrangement.

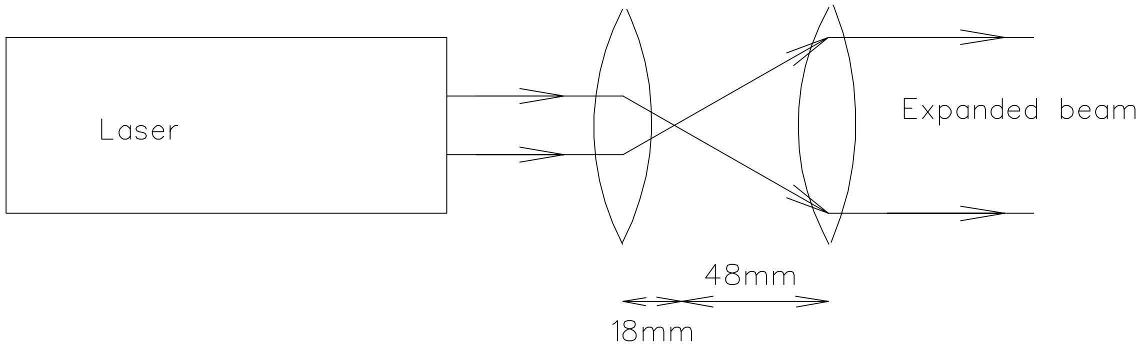

Figure 7.1 – Beam spreader arrangement.