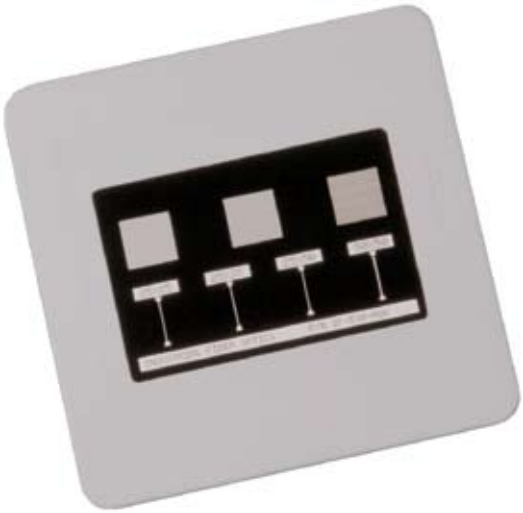
Diffraction Mosaic

Experiment Guide



Experiments include: Knife Edge
Single-Slit
Double-Slit
Multiple-Slit or Array

Model Number:
IF 508

INDUSTRIAL FIBER OPTICS

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INTRODUCTION

To a casual observer, light in the world around us seems to travel in a straight line. The appearance of shadows and reflections in mirrors seems to support this conclusion. The behavior of light in these instances can be explained with ordinary geometry. Light is either reflected, absorbed, scattered, or some combination of the three, but the path it takes can be traced using straight lines and angles.

In reality, light also has properties normally associated with the motion of waves observed in nature, such as ripples on a lake or pond. Occasionally we see evidence of light's wave properties, such as the colors on a soap bubble or a thin layer of oil floating on water. The effect of polarized sunglasses to reduce the glare from water, or the colors we see in a rainbow are further evidence of the wave characteristics of light.

In this experiment guide we will demonstrate the wave properties of light using a laser, some ordinary household items and a diffraction mosaic. We will start with a basic demonstration of diffraction (light bending around a corner) using a laser and knife (razor) blade edge. Our experiments will then progress to more dramatic visual effects that result from wave interference (light waves being added and subtracted) with single-slit, double-slit and multiple-slit apertures.

The wave properties of light, including the phenomenon of interference, were proven experimentally in 1801 by an English physicist and physician named Thomas Young (1773-1829). Young assumed that light traveled in a way similar to sound waves and that different colors were caused by changes in wavelength. In Young's experiment, light was passed through a series of narrow slits and projected onto a screen. The result was a pattern of light and dark regions known as diffraction fringes. These fringes were caused by the additive and subtractive effects of interference that could only occur if light was traveling as a wave. His findings eventually were confirmed by French engineer Augustin Fresnel — but initially were challenged by contemporary scientists who preferred [the more popular] Isaac Newton's theory that light was "corpuscular" or particle-like in nature.

The diffraction mosaic pictured on the front cover of this manual is a mounted photographic film containing precisely etched lines or slots. These are arranged as a set of four double-slit lines and three multiple-slit arrays. The mosaic will greatly aid in demonstrating the wave properties of light by reducing the effort and errors for experimental setup. The visual results will be more impressive, too. Using Industrial Fiber Optics' Diffraction Mosaic and experiment guide you will learn about the hidden effects in the light around us.

KNIFE EDGE DIFFRACTION

When a beam of light is partially blocked by some object, a shadow is created. Under special circumstances it can be shown that an obstruction actually causes diffractive effects related to the wave properties of light. Figure 1 shows what occurs when an obstruction with an opening in it is placed in the path of a wave front. When the wave passes through the opening it diffracts or behaves as if a new source of waves (a secondary wavefront) was created at the obstruction. Notice how the waves spread out beyond the actual size of the opening.

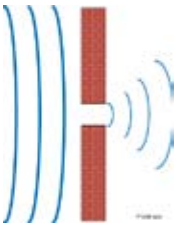


Figure 1.
Waves diffracting as they pass through an aperture.

The following experiment will demonstrate diffraction of a light beam by showing how light can bend around a corner. Subsequent procedures will produce increasingly dramatic effects from light's wave properties.

Equipment Needed:

- Helium neon laser with 632.8 nm emission wavelength*
- Single-edge razor blade

* Other helium neon lasing wavelengths and other visible gas lasers will work also, but the examples used in this manual assume the use of the 632.8 nm helium neon laser. (Diode lasers will also work for this experiment, but the interference fringes will not be as sharp.)

The procedures in this manual are written for use with Industrial Fiber Optics helium neon lasers. You may need to adjust the steps slightly to accommodate other manufacturers' lasers.

Procedure:

1. Review the laser safety rules on the back cover of this manual.
2. Find a table approximately 600 × 900 cm (2 × 3 feet) or larger in size from which the laser can be pointed toward a wall or other dull reflecting surface. The distance from the laser to the surface should be approximately three meters (10 feet).
3. Push the laser beam stop handle downward to its closed position and make sure its ON/OFF switch (SW) is in its OFF position. (The push button should be in its extended position.)
4. Plug the 110 VAC-to-DC power adapter (provided with the laser) into an AC wall outlet.
5. Insert the cord from the power adapter into the power jack (PWR) located on the rear of the laser.

6. Depress the ON/OFF switch (SW) on the control panel of the laser until it clicks into the ON position. (The switch should be slightly depressed.)
7. The pilot light (green LED) just to the right of the ON/OFF switch should now be lit, showing that the laser is on.
8. Push the laser's beam stop handle upward, to its open position.
9. Observe the red beam striking the wall, or other surface, in the direction which the laser is pointed.
10. Tape the single-edge razor to a book or wood block so the sharp edge is perpendicular to the tabletop. Make certain the razor is high enough to block the laser beam if you slide the razor's edge into the path of the beam. The sharp edge of the blade must extend past the edge of the book or block.

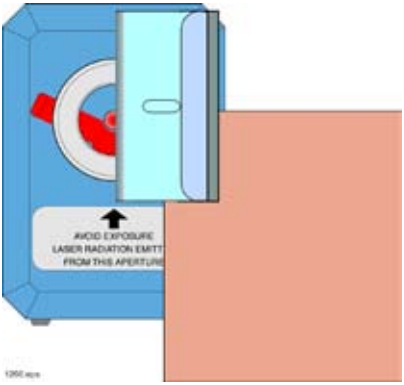


Figure 2.
Single-edge razor blade and its relationship to the laser.

11. Dim the room lights and slide the razor blade until its edge almost completely blocks the beam.
12. At this point (you must look very carefully) you should see a streak of light on the wall that is perpendicular to the vertical edge of the razor blade. If you position the razor blade carefully you will see a pattern of bright and dark areas in the light streak as shown in Figure 3.
13. Turn on the room lights, then push the beam stop handle on the laser down to its closed position. Turn off the laser and put away all the materials used in this experiment.

Results:

When you obstructed the laser beam with the sharp edge of the razor, you created a secondary wavefront at the edge of the razor. The light streak you observed was the result of light waves spreading from the second wavefront created at the razor's edge. The light and dark areas in the streak occur where waves from the unobstructed portion of the original beam interfere with those from the secondary wavefront.

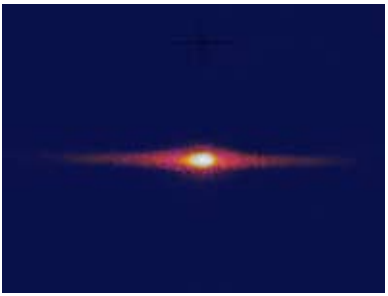


Figure 3.
Laser beam pattern from single-edge razor edge.

SINGLE-SLIT DIFFRACTION

If you place a second razor blade parallel to the single blade in the previous experiment and form a single narrow slit between their edges, you will observe a stronger diffraction pattern of bright and dark areas. When a laser beam passes through a narrow parallel slit, each razor edge produces an identical diffraction pattern. If the slit edges are close enough to each other, the diffraction patterns overlap and interference occurs.

The following experiment will demonstrate the change in diffraction pattern when a second knife edge is placed in the laser beam. The resulting pattern will be brighter and more defined than with a single knife edge.

Equipment Needed:

- Helium neon laser with 632.8 nm emission wavelength*
- Single-edge razor blades (2)

* Other helium neon lasing wavelengths and other visible gas lasers will work also, but the examples used in this manual assume the use of the 632.8 nm helium neon laser. (Diode lasers will also work for this experiment, but the interference fringes will not be as sharp.)

Procedure:

1. Review the laser safety rules on the back cover of this manual.
2. Select a table approximately 600 × 900 cm (2 × 3 feet) or larger in size from which the laser can be pointed toward a wall or other dull reflecting surface. The distance from the laser to the surface should be approximately three meters (10 feet).
3. Push the laser beam stop handle downward to its closed position and make sure its ON/OFF switch (SW) is in its OFF position. (The push button should be in its extended position.)
4. Plug the 110 VAC-to-DC power adapter (provided with the laser) into an AC wall outlet. Plug the cord from the power adapter into the power jack (PWR) located on the rear of the laser.
5. Depress the ON/OFF switch (SW) on the control panel of the laser until it clicks into the ON position. (The switch should be slightly depressed.) The pilot light (green LED) just to right of the ON/OFF switch should now be lit, showing that the laser is on.
6. Push the laser's beam stop handle upward, to its open position. Observe the red beam striking the wall, or other surface, in the direction which the laser is pointed.
7. Tape a single-edge razor to a book or wood block so the sharp edge is perpendicular to the table top. Make certain the razor is at a height sufficient

to block the beam when you slide the razor's edge into the beam's path. The sharp edge of the blade must extend past the edge of the book or block.

8. Repeat Step 7 with the second single-edge razor.
9. Dim the room lights and slide the first razor blade edge sideways until the laser beam is almost completely blocked.

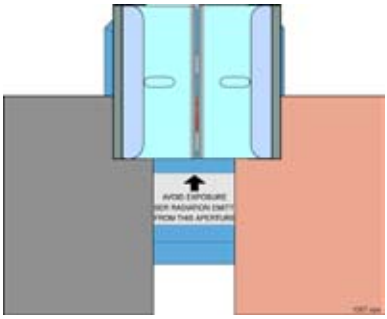


Figure 4.
Two single-edge razor blades positioned properly to create diffraction pattern from a laser beam.

10. At this point you should see on the wall a streak of light that is perpendicular to the razor blade edge, as in the previous experiment. If you position the razor blade carefully, you will see a pattern of bright and dark areas in the light streak.
11. Slide the second razor blade edge slowly into the other side of the laser beam. Position the second razor's edge parallel to the edge of the first one. Slide the second blade toward the first until a narrow slit is formed between the two blades. A significant change should occur in the diffraction pattern once the blades are sufficiently close to each other. Change the blade spacing and observe the brightness and distance between the light and dark areas in the pattern.
12. Turn on the room lights, then push the laser's beam stop handle down to its closed position. Turn off the laser and put away all the materials used in this experiment.



Figure 5.
Diffraction pattern created by two razor blades.

Results:

When you moved another razor blade edge into the laser beam, a secondary wavefront was created, just as with the first razor. The wavefronts from both razor edges traveled toward the wall and interfered with each other. Where the interference was constructive (additive), a bright spot appeared on the wall. The dark regions between the spots were the result of destructive (subtractive) interference. The patterns of bright and dark spots are known as diffraction fringes.

As you varied the slit widths, the spacing between fringes also changed. The distance between the razor blade edges changes the location of constructive and destructive interference. The spacing between fringes is related to the distance between the obstructing razor edges, the laser beam path length to the wall and the wavelength of the laser light. We will explore this mathematical relationship in the next experiment.

DOUBLE-SLIT DIFFRACTION

When you placed a razor blade parallel to another in the previous experiment and formed a single narrow slit, you observed a stronger diffraction pattern of bright and dark areas. When a laser beam is sent through two equally narrow parallel slits, each slit produces an identical diffraction pattern. If the slits are close enough together, the diffraction patterns overlap and interference occurs. A double slit will produce a pattern brighter than either the knife edge or a single slit.

In the following procedure we will observe and examine the diffraction and interference patterns produced by a laser beam when it passes through double slits with different widths and spacing. We will perform some simple measurements that will allow you to accurately determine the spacing between the parallel slits on the diffraction mosaic.

Equipment Needed:

- Helium neon laser, 632.8 nm emission
- Diffraction mosaic
- Masking tape
- Ruler and tape measure (metric or SAE)

Procedure:

1. Pick a table approximately 600 × 900 cm (2 × 3 feet) or larger in size to conduct this experiment. Place the laser on the table and point it toward a vertical wall or dull reflecting surface. The distance from the laser to the surface should be approximately three meters (10 feet).
2. Push the laser beam stop handle downward to its closed position and make sure its ON/OFF switch (SW) is in its OFF position.
3. Plug the 110 VAC-to-DC power adapter (provided with the laser) into an AC wall outlet. Plug the cord from the power adapter into the power jack (PWR) located on the rear of the laser.
4. Depress the ON/OFF switch (SW) on the control panel of the laser until it clicks into the ON position.
5. Push the beam stop handle upward, to its open position. Observe the red beam striking the wall, or other surface, in the direction which the laser is pointed.
6. Tape the diffraction mosaic fiberboard holder to a book or block so the vertical slits are perpendicular to the table top. Make certain the mosaic is at a height where the laser beam will pass through the center of the vertical slits.
7. Slide the diffraction mosaic so the laser beam passes through the vertical slits labeled 25 × 25. At this point you should see a series of red dots or patterns on the wall.

8. Measure the distance from the diffraction mosaic to the wall, r, with a tape measure and record the distance in column 2 row 1 of Table 1. Now measure the distance (s) between the centers of the red dots on the wall using a ruler. Record the distance (s) in Table1.

9. Slide the diffraction mosaic so the laser beam passes through the remaining slit pairs (25 × 35 through 50 × 50) and complete rows 3 through 5 of Table 1.

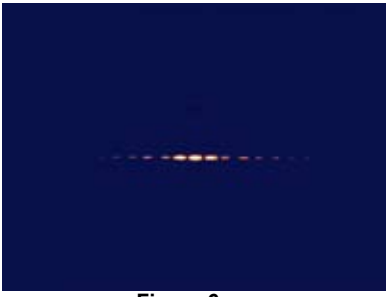


Figure 6.
Laser diffraction pattern from dual slit.

Table 1.

Slit pair	Distance (r)	Separation (s)	Calculated Width	(d) Meters
25 x 25				4.5×10^{-5}
25 x 35				5.8×10^{-5}
25 x 50				7.5×10^{-5}
50 x 50				10.0×10^{-5}

10. In his experiment Thomas Young determined a well-known equation that relates the separation between fringes to the distance between the slits. The formula is as follows:

$$d = \frac{\lambda}{\sin\phi}$$

λ = The lasing wavelength passing through the slits (632.8 x 10-9 for HeNe)

d = The distance in meters between slits

$\sin\phi$ = The separation between fringes on the screen divided by the distance from the slits to the screen (s/r)

11. From the equation you can see that given any three numbers, the fourth number can be determined. Calculate the distance between the slits on the diffraction mosaic. Record your findings in the fourth column of Table 1.

Results:

The HeNe laser has a precisely known wavelength which – along with your measurements – can be used to determine the separation of the slits with reasonable accuracy. The greater the distance between the slits and the wall when you measure the spacing between fringes, the less likely you are to encounter measurement errors. The spacing between slits on the diffraction mosaic will vary slightly, but the nominal spacing is as shown in the last column of Table 1.

MULTIPLE-SLIT OR ARRAY DIFFRACTION

When a laser beam is transmitted through a group of equally narrow parallel slits, all slits produce identical diffraction patterns. If the slits are close enough together, the diffraction patterns overlap and interference occurs. Just as the double slit will give a brighter pattern than a knife edge or a single slit, the additional light coming from a multiple slit or array grating will further intensify the brightness of the observed pattern. In the following procedure we will observe the interference patterns generated by three diffraction grating arrays and calculate the spacing of the slits.

Equipment Needed:

- Helium neon laser, 632.8 nm emission
- Diffraction mosaic
- Masking tape
- Ruler and tape measure (metric or English)

Procedure:

1. Find a table approximately 600 × 900 cm (2 × 3 feet) or larger in size on which to place the laser and point it toward a wall or other dull reflecting surface. The distance from the laser to the surface should be approximately three meters (10 feet).
2. Push the laser's beam stop handle downward to its closed position and make sure its ON/OFF switch (SW) is in its OFF position.
3. Plug the 110 VAC-to-DC power adapter (provided with the laser) into an AC wall outlet. Plug the cord from the power adapter into the power jack (PWR) located on the rear of the laser.
4. Depress the ON/OFF switch (SW) on the control panel of the laser until it clicks into the ON position. (The switch should be slightly depressed.) The pilot light (green LED) just to right of the ON/OFF switch should now be lit, showing that the laser is on.
5. Push the beam stop handle upward, to its open position. Observe the red beam striking the wall, or other surface, in the direction which the laser is pointed.
6. On the diffraction mosaic notice there is a set of three rectangular areas. For the grating experiment you will be using these three rectangular areas.
7. Tape the diffraction mosaic fiberboard holder to a book or block so the gratings are perpendicular to the table top. Make sure the mosaic is high enough so the laser beam will pass through the center of the gratings.
8. Slide the diffraction mosaic so the laser beam passes through the 25 lines/mm grating. (Note: this is the grating just above the vertical slits labeled 25 × 25.)

9. At this time you should see a series of red dots or patterns on the wall as shown in Figure 7.

10. Measure the distance from the diffraction mosaic to the wall, r, with a tape measure and record that distance in column 2 row 1 of Table 2. Now measure the distance between the centers of the red dots on the wall and record the distance in Table 2.



Figure 7.
Optical beam pattern from the laser beam and the multiple slit array.

11. Slide the diffraction mosaic so the laser beam passes through the other gratings (50 lines/mm and 100 lines/mm), then complete rows 2 and 3 of Table 2.

Table 1.

Gratings (lines/mm)	**Distance** (r)	**Separation** (s)	**Calculated Width**
25			
50			
100			

12. Using the equation from the previous experiment, calculate the distance between the slits on the diffraction gratings. Record your results in Table 2.

$$d = \frac{\lambda}{\sin\phi}$$

λ = The lasing wavelength passing through the slits (632.8 x 10-9 for HeNe)

d = The distance in meters between slits

sin ϕ = The separation between fringes on the screen divided by the distance from the slits to the screen (s/r)

Results:

The intensity of the diffraction pattern on the wall should have been significantly brighter than with the double slits. As noted before, the HeNe laser has a precisely known wavelength which, along with your measurements, can be used to determine the separation of the grating slits with reasonable accuracy. The longer the distance between the gratings and the wall when you measure the spacing between fringes, the less likely you are to introduce error.

Diffraction gratings are an important optical element used for separating component wavelengths in an optical source, and for providing a compact method of generating optical patterns.

Rules for Laser Safety

- Lasers produce a very intense beam of light. Treat them with respect. Most educational lasers have an output of less than 3 milliwatts, and will not harm the skin.
- Never look into the laser aperture while the laser is turned on! PERMANENT EYE DAMAGE COULD RESULT.
- Never stare into the oncoming beam. Never use magnifiers (such as binoculars or telescopes) to look at the beam as it travels – or when it strikes a surface.
- Never point a laser at anyone's eyes or face, no matter how far away they are.
- When using a laser in the classroom or laboratory, always use a beam stop, or project the beam to areas, which people won't enter or pass through.
- Never leave a laser unattended while it is turned on – and always unplug it when it's not actually being used.
- Remove all shiny objects from the area in which you will be working. This includes rings, watches, metal bands, tools, and glass. Reflections from the beam can be nearly as intense as the beam itself.
- Never disassemble or try to adjust the laser's internal components. Electric shock could result.