Interference, Diffraction & Polarization

Produced by the Physics Staff at Collin College

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**Purpose**

In this experiment, you will investigate interference, diffraction, and polarization of light. You will use a series of vertical slits to study interference and diffraction, and a set of two polarizers to study the polarization of the light. We will further study diffraction by using a diffraction grating.

**Equipment**

- Slit plate
- (3) Component holders
- Ray table component holder
- Diffraction grating
- Diffraction plate
- Ray table and base
- Two polarizers
- Optical bench
- Light source
- Diffraction scale
- Cylindrical lens
- Color filters (three colors)
- Slit mask
- Crossed arrow target

**Theory**

In the early 1700s there were two conflicting theories concerning the nature of light. Isaac Newton believed that the straight-line travel of light rays could best be explained by assuming that light was a stream of very small "corpuscles" traveling at great speed away from a light source. Christian Huygens rejected Newton's particle idea and proposed that light was a longitudinal wave created by a light source and moving out in an ever increasing spherical wavefront through the "ether." Both theories had advocates, but the majority sided with the more famous Newton, and his particle theory of light reigned supreme during the 18th century.

In the early 1800s, however, Thomas Young shattered Newton's corpuscular theory with convincing evidence that light was a wave. But it behaved as a transverse wave, not a longitudinal wave as Huygens had proposed. Young’s evidence consisted of three distinctly different effects that everyone agreed could be produced only by a transverse wave. These effects were interference, diffraction, and polarization. Young's wave theory of light then ruled during the entire 19th century.

But in the early 1900s, a young Albert Einstein successfully explained the photo-electric effect (which had baffled physicists because it did not fit the wave theory of light) by assuming that light was indeed a stream of small particles which he called photons.

It wasn't until the 1920s that the bewildering back-and-forth argument over the true nature of light was put to rest. The quantum mechanical theory of matter proposed that all electromagnetic radiation, including light, displayed either particle or wave properties, depending on how it was observed. This theory has successfully passed all experimental tests for the past 70 years.
**Interference**

Young’s interference demonstration is illustrated in Figure 13.1. Light waves emanating from a small source strike screen 1 which contains two small apertures $S_1$ and $S_2$. The source is equidistant from the apertures so the waves arriving at $S_1$ and $S_2$ are in phase with each other.

Each aperture acts as a new source of waves which leave screen 1 (while in phase) and subsequently interfere with each other.

The interference creates the pattern shown in the figure: each small dot indicates a moving point of constructive interference. Note that the dots form rows which diverge as the waves move out. The interference pattern is made visible when the waves strike screen 2, creating an alternating series of bright and dark spaces.

If the apertures in screen 1 are small round holes, the interference is three dimensional and the pattern on screen 2 is a pair of overlapping circular waves. The radial spokes of constructive and destructive interference are clearly visible.

If the apertures in screen 1 are narrow parallel slits, the interference is two dimensional and the pattern on screen 2 is a series of alternating parallel bright and dark straight lines, as shown in Figure 13.2.

In this experiment, you will place your eye in the position on screen 2 and look through two narrow vertical slits at a light source. The interference pattern will be formed directly on the retina of your eye. You will see the pattern superimposed on a horizontal illuminated scale.

The geometry is slightly more complicated than it would be if the pattern were projected onto a screen, as it is in most textbook examples. The essential geometry is shown in Figure 13.3.
At the zeroth maxima on your retina (the center bright line), light rays from slits $S_1$ and $S_2$ (points $A$ and $B$) have traveled the same distance to your eye so they are in phase and they interfere constructively. At all the other maxima, light from one slit has traveled a whole number of wavelengths farther than light from the other slit, so the rays are again in phase, and constructive interference occurs.

In the figure, the line $AC$ is constructed perpendicular to the line $BP$. Since the slits are very close together (in the actual screen 1, not in the figure), lines $AP$ and $BP$ are nearly parallel. Therefore, to a very close approximation, $AP = CP$. This means that, for constructive interference to occur at $P$, it must be true that $BC = n\lambda$.

From right triangle $ACB$, you can see that $BC = AB \sin \theta$, where $AB$ is the distance between the two slits on screen 1. Therefore, $AB \sin \theta = n\lambda$. The spacing between the slits, $AB$, is stated on the screen. Therefore, you need only measure the value of $\theta$ for a particular value of $n$ to determine the wavelength of light.

To measure $\theta$, notice that the dotted lines in the figure show a projection of the interference pattern onto the scale (as it appears when looking through the slits). Notice that $\theta' = \arctan \frac{X}{L}$.

You can also show from the diagram that, if $BP$ is parallel to $AP$ as we have already assumed, then $\theta' = \theta$. Therefore, $\theta = \tan^{-1} \frac{X}{L}$; and $AB \sin (\tan^{-1} \frac{X}{L}) = n\lambda$, which is easily solved for $\lambda$.

**Diffraction**

1. The Diffraction Grating

Diffraction gratings are used to make very accurate measurements of the wavelength of light. In principle, they function much the same as the two-slit aperture. However, a diffraction grating has many very narrow slits that are very closely spaced. By using very narrow slits, the pattern is spread out to large angles, allowing measurements to be made more accurately. In spreading out the available light to large angles, however, you lose brightness. The use of many slits provides many sources of light, and brightness is preserved.

In this experiment you will use a diffraction grating to determine the range of wavelengths for each of the colors in the visible spectrum. Figure 13.4 shows the geometry of the pattern you see with a diffraction grating. The trigonometry is the same as that of the double slit except that in the pattern on screen 2, each order of maximum intensity is a complete visible
spectrum instead of simply a bright line. In Figure 13.4, $A$ is the distance between two adjacent slits. Therefore, $A \sin \theta = n\lambda$, or $A \sin (\tan^{-1} \frac{X}{L}) = n\lambda$.

2. Single Slit Diffraction

If you look closely at a two-slit interference pattern, you will notice that the intensity of the fringes varies. This variation in intensity forms an interference pattern of its own that is independent of the number of slits or the separation between the slits. In fact, two slits are not required to see this pattern; it can be seen most clearly when light passes through a single, narrow slit.

The single slit pattern can be explained using Huygen’s theory. When a plane wavefront strikes the slit, each wavefront point in the slit acts as a point source of light. Figure 13.5 shows a single slit in screen illuminated by a point source beyond the figure to the far left, and the resulting diffraction pattern on screen 2.

The distance $AP = BP + \lambda$. Since light from point $A$ travels one wavelength farther than light from point $B$, the light from these two points is in phase at point $P$. Therefore light reaching point $P$ from the points in between $A$ and $B$ will vary in phase through a full $360^\circ$. In particular, light coming from the midpoint of the slit will reach point $P$ $180^\circ$ out of phase with light from $A$ and $B$. For any point source within the lower half of the slit (from which light reaches point $P$ at a particular phase), there will be a corresponding point within the upper half from which light arrives at $P$ in the exact opposite phase. Because of this, there is complete cancellation at point $P$, and you will see a minimum (dark fringe) at that point.

In the figure, point $P$ is at an angle $\theta$ from the center of the slit. We make the assumption that $P$ is far enough away from the slit that lines $AP$ and $BP$ are very nearly parallel (this is true in reality; if not in the figure). Angle $ABC = \theta$, also. Therefore $AB \sin \theta = \lambda$ where $AB$ is the
width of the slit. A similar argument can be used to show that a minimum will be found at any angle such that $AB \sin \theta = n\lambda$ or $AB \sin (\tan^{-1} \frac{X}{L}) = n\lambda$, where $n$ is any integer and is called the order of the minimum.

In this experiment you will compare the single-slit diffraction pattern with the two-slit interference pattern, and then use the single-slit pattern to measure the wavelengths of red, green, and blue light.

**Polarization**

Light is a transverse wave; that is, the electric and magnetic fields that comprise a light wave are perpendicular to the direction of propagation (see Figure 13.6). The direction of polarization refers to the direction of the electric field. The magnetic field is always perpendicular to the electric field. Figure 13.6 (b) and (c) show vertical and horizontal polarization, respectively. Figure 13.6 (d) depicts random polarization which occurs when the direction of polarization changes rapidly with time, as it does in the light from most incandescent light sources.

Your optics equipment includes two polarizers, which transmit only light that is plane polarized along the plane defined by the $0^\circ$ and $180^\circ$ marks on the polarizer scales. Light that is polarized along any other plane is absorbed by the polarizer. Therefore, if randomly polarized light enters the polarizer, the light that passes through is plane polarized. In this experiment, you will use the polarizers to investigate the phenomena of polarized light.
Procedure

In this lab, we will be using a component called a *diffraction plate*. This plate has a series of single and double slits etched from an opaque background. The width and separation of the slits are as follows:

<table>
<thead>
<tr>
<th>Pattern</th>
<th># of Slits</th>
<th>Slit Width (mm)</th>
<th>Slit Spacing center-to-center (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>0.04</td>
<td>0.125</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>0.04</td>
<td>0.250</td>
</tr>
<tr>
<td>F</td>
<td>2</td>
<td>0.08</td>
<td>0.250</td>
</tr>
</tbody>
</table>

A. Interference

1. Set up the Equipment as shown in Figure 13.7. Center the Slit Mask in the Component Holder. Look through the Slit Mask and adjust the position of the scale so you can see the filament of the Light Source through the slot in the scale.
2. Attach the Diffraction Plate to the back side of the Component Holder as shown. Center pattern $D$, with the slits vertical, in the aperture of the Slit Mask. Record the slit separation $AB$ in Table 13.1. Look through the slits. By centering your eye so that you look through both the two slits and the window of the Diffraction Plate, you should be able to clearly see the interference pattern superimposed on the illuminated scale.

3. Measure and record the distance $L$ between the diffraction plate and the scale.

4. Place the red color filter over the light source aperture and look through the slits at the pattern on the scale. Record the distance $X$ on the scale to each of the first five maxima of the pattern (or as many as you can see up to five).

5. Repeat step 4 using the green filter and then again using the blue filter.

6. Calculate and record the wavelength of the red, green, and blue light.

**B. The Diffraction Grating**

1. With the equipment arranged as in Part A, remove the Diffraction Plate and the Slit Mask and replace them with the Diffraction Grating. Look through the grating and observe the first order spectrum (to the right and left of the filament). Record (in Table 13.2) the grating spacing $A$.

2. Move the scale toward the diffraction grating until the entire first order spectrum fits on the scale. Record the distance $X$ on the scale from the filament to the violet $X_v$ and red $X_r$ ends of the first order spectrum.

3. Record the distance $L$ between the grating and the scale.

4. Calculate and record the wavelength range (violet $\lambda_v$ to red $\lambda_r$). Compare your results with textbook values by calculating the percent error of your experimental wavelengths.

**C. Single Slit Diffraction**

1. With the equipment arranged as in Part A (replace the diffraction grating with the diffraction plate and slit mask), look through the single slit aperture labeled B in the Diffraction Plate. Record the slit width $AB$ in Table 13.3.
2. Place the red color filter over the light source aperture and look through the slits at the pattern on the scale. Record the distance $X$ on the scale to each of the first three minima of the pattern (or as many as you can see up to three).

3. Repeat step 2 using the green filter and then again using the blue filter.

4. Record the distance $L$ between the diffraction plate and the scale.

5. Calculate and record the wavelength of the red, green, and blue light. Calculate and record the % difference between your wavelength values from Parts A and C.

D. Polarization

1. Setup the equipment as shown in Figure 13.8. Switch the light source on and view the Crossed Arrow Target with both Polarizers removed. Place Polarizer $A$ on the Component Holder. Rotate the polarizer while viewing the target. Record your observations in Table 13.4 by answering the following question: Does the target seem as bright when looking through the polarizer as when looking directly at the target? Why?

![Figure 13.8](image)

2. Align Polarizer $A$ so it transmits only vertically polarized light. Place Polarizer $B$ on the other Component Holder. Rotate Polarizer $B$ while looking through both polarizers. Record your observations in Table 13.4 by answering the following question: For what angles of polarizer $B$ is a maximum of light transmitted? For what angles is a minimum of light transmitted?