Optics Experiment 9 – Wave Properties of Light
Two-Slit Interference

Light has both particle and wave properties. So far we have concentrated on the wave properties of light beams where it mattered (as in polarization). In this experiment we will continue our exploration of the wave nature of light. We will explore *interference* – what happens when light beams are combined. We'll also measure the wavelength of light and examine how wavelength varies with the color of light.

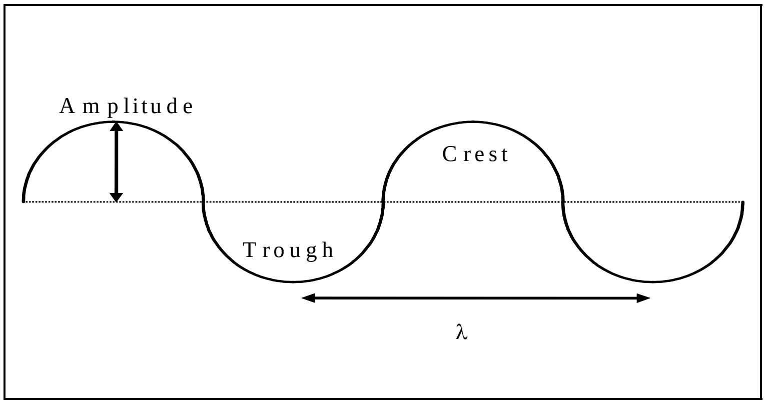


Figure 1. Characteristics of a light wave.

For the purposes of this procedure we will again assume that the wave properties of a beam of light dominate. The wavelength of light (λ) is related to its color. In the visible spectrum which extends from approximately 400 - 700 *nanometers* (a nanometer is 10^{-9} meters), longer wavelengths correspond to red and orange and shorter wavelengths correspond to violet and blue. You have probably heard about *ultraviolet* light and its associated dangers in relationship to the depletion of the earth's ozone layer. This is light with wavelengths in the 100 to 400 nanometer range. Wavelengths from 1 millimeter to 10 microns (10^{-3} to 10^{-7} meters) are known as *infrared* light.

The frequency of a light wave (f) is equal to the speed of light in free space (c) divided by its wavelength in free space (λ): $f = c/\lambda$. Since the speed of light in free space is constant ($c = 3 \times 10^8$ m/s) the longer the wavelength the lower the frequency. All visible light waves have frequencies of around 10^{15} Hz.

In two-slit interference, light falls on an opaque screen with two closely spaced, narrow slits. Each slit then acts as a new source of light. Because the slits are illuminated by the same wave front, the sources are in phase. The places where the wave fronts from the two sources overlap form interference patterns. In general we are concerned with two types of interference: constructive and destructive.

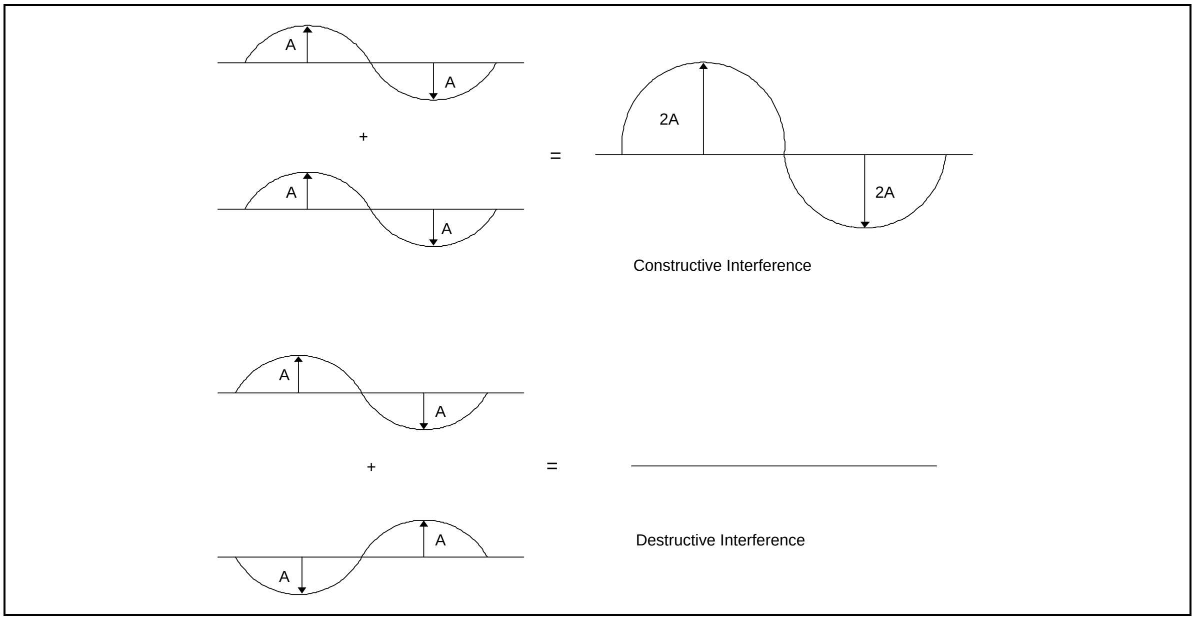


Figure 2. Interference in waves.

Equipment needed

- Optics bench
- Diffraction plate
- Ray table base
- Light source
- Diffraction scale
- Slit mask

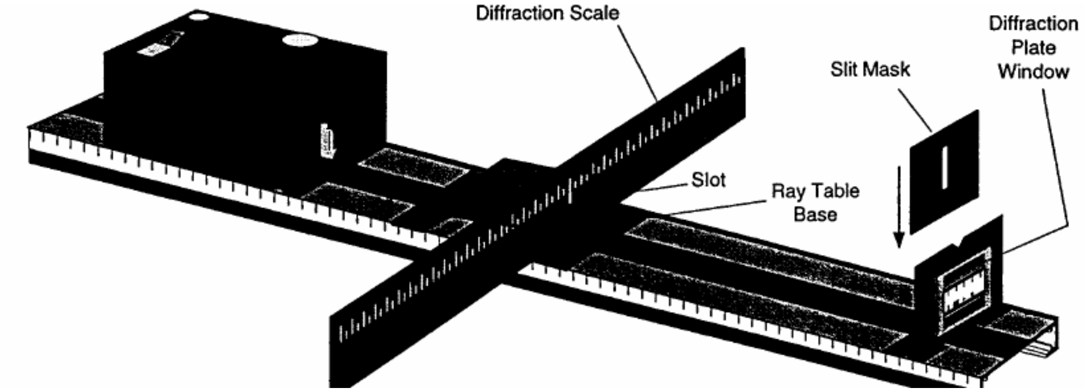


Figure 3 (Courtesy of PASCO)

Procedure

Set your lab equipment as shown in Fig 3. The slit mask should be centered on the component holder. While looking through the slit mask, adjust the position of the diffraction scale so the filament of the light source is visible through the slot in the diffraction scale.

Attach the diffraction plate to the other side of the component holder as shown. Center pattern D with the slits vertical in the aperture of the slit mask. Look through the slits. By centering your eye so that you look through both the slits and the window of the diffraction plate, you should be able to see clearly both the interference pattern and the illuminated scale on the diffraction scale.

The geometry of this experiment is shown in Fig 4. At the zeroth maxima light rays from slits A and B have traveled the same distance from the slits to your eye. They are then in phase and interfere constructively on your retina. At the first order maxima, light from slit B has traveled one wavelength farther than from slit A. These rays are again in phase and constructive interference occurs at this position.

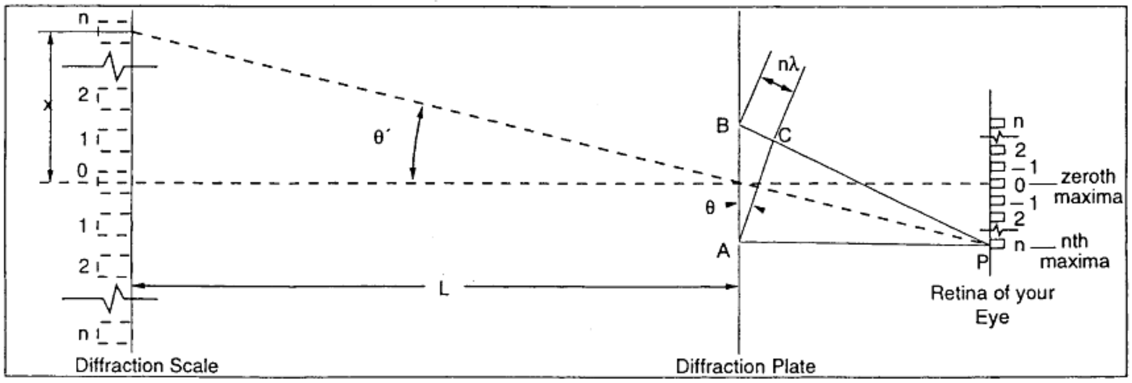


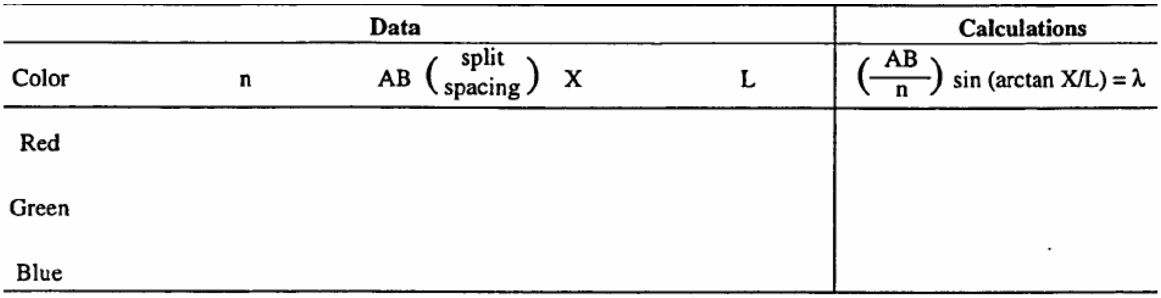
Figure 4 (Courtesy of PASCO)

At the nth order maxima, light from slit B has traveled n wavelengths farther that the light from slit A and again constructive interference occurs. In Fig. 4 line **AC** is constructed perpendicular to line **PB**. Because the slits are very close together (in the experiment) lines **AP** and **BP** are nearly parallel. Therefore, to a very close approximation, **AP** = **CP**. This means for constructive interference to occur at P, it must be true that **BC** = $n\lambda$.

From right triangle ACB, it can be shown that **BC** = **AB** $\sin\theta$, where A is the distance between the slits on the diffraction plate. Therefore, **AB** $\sin\theta = n\lambda$. You need only measure the value of θ for a particular value of n to determine the wavelength of light.

To measure θ, notice that the dashed lines in Fig. 4 show a projection of the interference pattern onto the diffraction scale. Note that $\theta' = \arctan X / L$. It can also be shown from the diagram that if **BP** is parallel to **AP** as we have already assumed, then $\theta' = \theta$. Therefore, $\theta = \arctan X / L$ and **AB** sin (arctan X/L) = nλ.

Recreate Table 1 in your lab notebook. Looking through the pair of slits (pattern D) at the light source filament, record the required measurements. Alternately place the red, green, and blue color filters over the light source aperture to make the measurements for the different colors of lights. If time permits, make measurements with the E and F patterns on the diffraction plate. Perform the calculations shown to determine the wavelength of red, blue and green light.



Data					Calculations
Color	n	AB $\left(\begin{smallmatrix}\text{split}\\ \text{spacing}\end{smallmatrix}\right)$	X	L	$\left(\frac{AB}{n}\right)$ sin (arctan X/L) = λ
Red					
Green					
Blue					

Table 1 (Courtesy of PASCO)

Optics Experiment 10 - The Diffraction Grating

Diffraction gratings are used to make very accurate measurements of the wavelength of light. In theory, they function much the same as two slit apertures like we have already used. However, a diffraction grating has many slits rather than two and they are very closely spaced. By using closely spaced slits, the light is *diffracted* or bent to large angles and measurements can be made more accurately. In spreading out the available light to large angles, however brightness is lost. By using many slits, many sources of light are provided 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.

- Optics bench
- Ray table base
- Diffraction scale
- Diffraction grating
- Any colored filter
- Light source
- Component holder
- Diffraction plate
- Slit mask

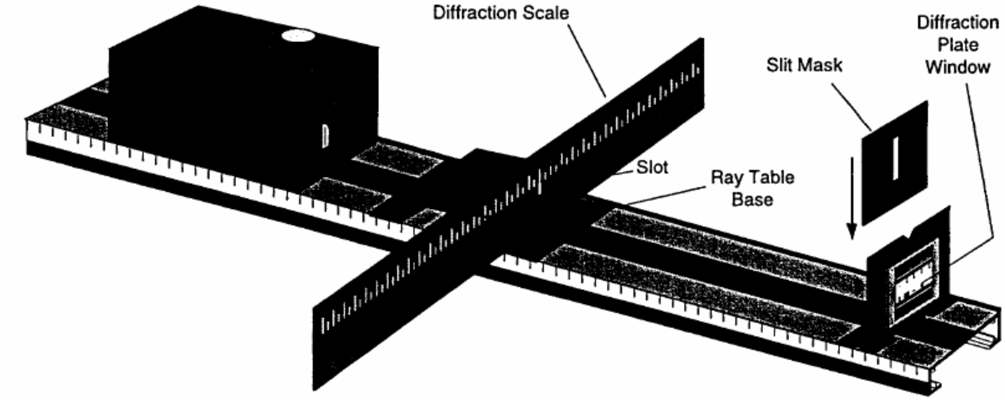


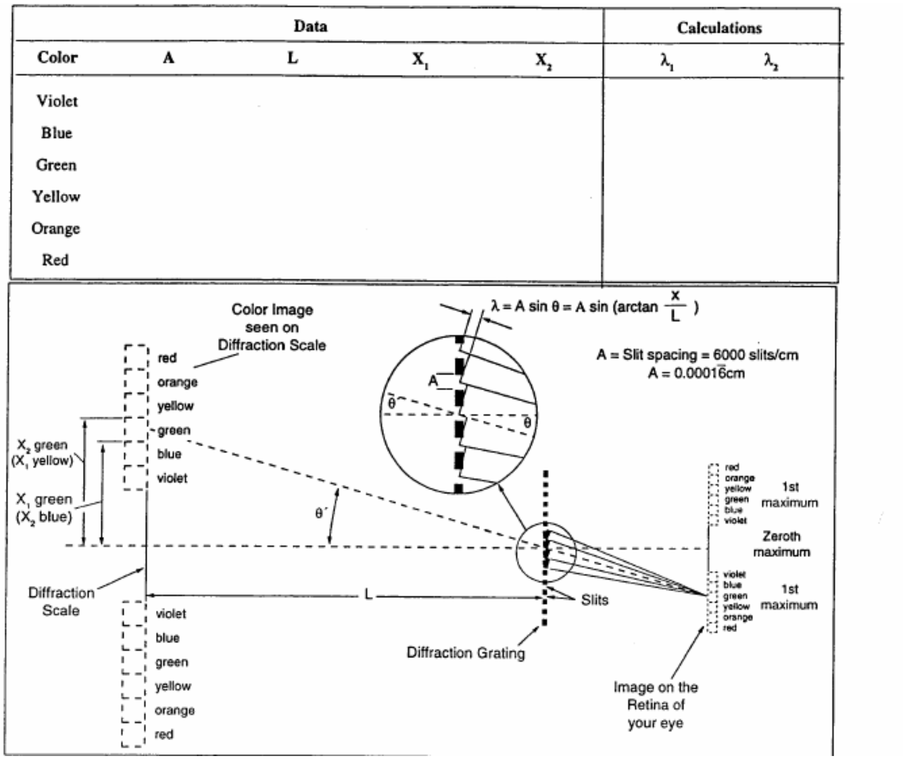
Figure 5 (Courtesy of PASCO)

Procedure

Arrange the equipment as shown in Fig. 5. When looking through the diffraction grating window, the filament of the light source must be directly visible through the slot in the diffraction plate. Look through each of the double slit patterns (D, E, and F) of the diffraction plate at the filament of the light source. Qualitatively, compare the spacing of the interference maxima for the different patterns.

1. How does the spacing of the maxima relate to the spacing of the slits on the diffraction plate (compare patterns of equal slit width, but different slit spacing)?

2. Look through the 10-slit pattern (pattern G) at the filament. What effect does the larger number of the slits have on the diffraction pattern?



Data					Calculations	
Color	A	L	X_1	X_2	λ_1	λ_2
Violet						
Blue						
Green						
Yellow						
Orange						
Red						

Figure 6 (Courtesy of PASCO)

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.

Reproduce the table in the top of Fig. 6 in your lab notebook. Record the data as required.

Compare your results with those of other students, or with textbook values.

1. Are your results in complete agreement? Can you account for any discrepancies?

2. What advantages are there in using wavelength rather than color to characterize visible light?

Optics Experiment 11 - Single Slit Diffraction

A careful examination of a two slit interference pattern one notices that the intensity of the fringes varies. This variation in intensity forms an interference pattern of its own which 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.

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

- Optics bench
- Ray table base
- Diffraction scale
- Diffraction grating
- Colored filters (red, green, and blue/green)
- Light source
- Component holder
- Diffraction plate
- Slit mask

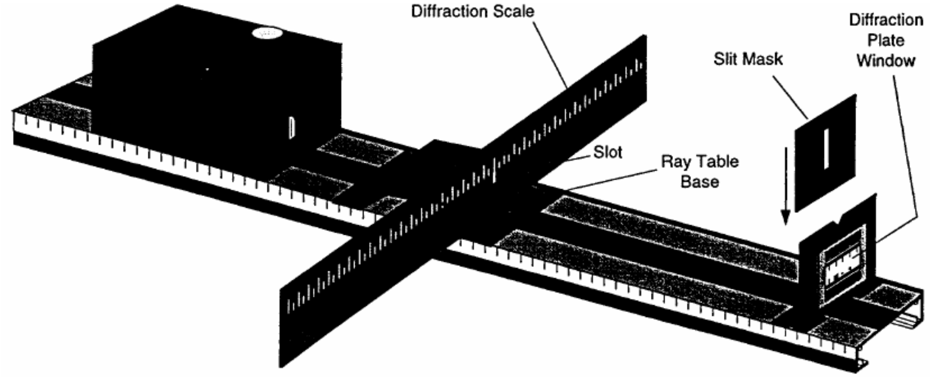


Figure 7 (Courtesy of PASCO)

Procedure

Setup the equipment as shown in Fig. 7. Look through each of the three single slit apertures in the diffraction plate (patterns A, B, and C). Examine the diffraction patterns with and without color filters over the aperture of the light source.

1. How does the spacing between fringes vary with the width of the slit?

Compare the single slit patterns with the double slit patterns.

2. How does a double slit interference pattern differ from a single slit pattern? (Compare patterns of equal slit widths, such as A vs. D or B vs. E.)

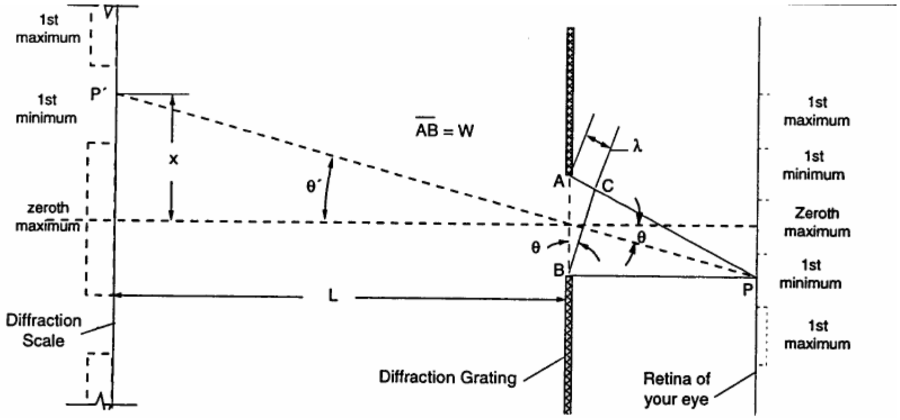


Figure 8 (Courtesy of PASCO)

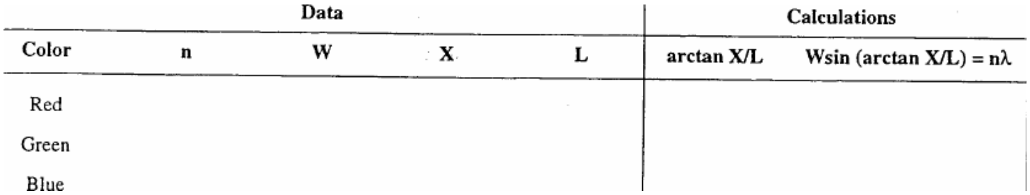
The single slit pattern can be explained using Huygen's theory. When a plane wave front strikes the slit, each point on the slit acts as a point source of light. Fig. 8 shows a point P far from the slit where the distance **AP** = **BP** + λ. Since light from point A travels one wavelength farther than light from point B, the light from these two points is in phase at point P. But light reaching point P from the points between A and B will vary in phase through a full 360 degrees. For any point from which light reaches point P at a particular phase, there will be a point in which light arrives in the exact opposite phase. Because of this, there is a complete cancellation at a point P and a minima (dark fringe) will be seen at that point.

In the figure, point P is at an angle q from the center of the slit. We make the assumption that point P is far enough away such that **AP** and **BP** are very nearly parallel (this is true in reality, if not in the diagram). As shown in the diagram, angle ABC = θ. Therefore $W \sin \theta = \lambda$; where W is the width of the slit (AB). A similar argument can be used to show that a minima will be found at any angle such that $W \sin \theta = n\lambda$, where n is any integer.

Review the two slit interference experiment. Notice the similarity between equations for single and double patterns. To measure the wavelength of light, use the same techniques you used in the two slit experiment ($\theta = \arctan X / L$). When measuring the distance to the minima (x) for each color, place the color filter on the front of the light source.

Reproduce Table 2 in your lab notebook and record the required information. Perform the calculations shown to determine the wavelength of red, green, and blue light.

3. If the width of the slit, W, were less than the wavelength of the light being used, how many maxima would you expect to see in the single slit diffraction pattern? Why?



Data					Calculations	
Color	**n**	**W**	**X**	**L**	**arctan X/L**	**Wsin (arctan X/L) = nλ**
Red						
Green						
Blue						

Table 2 (Courtesy of PASCO)

Optics Experiment 12 - General Diffraction

The simplest diffraction patterns are produced by narrow slits. However, any aperture, or collection of apertures, will produce a diffraction pattern if the dimensions of the apertures are of the same order of magnitude as the wavelength of visible light.

The diffraction pattern created by a particular aperture can be determined quantitatively using Huygen's principle. Simply treat each aperture as a collection of point sources of light (small, closely packed points will give the best approximation of the diffraction pattern). At any position on your viewing screen, determine the phase of the light contributed by each point on the aperture. Finally, use the superposition principle to sum the contributions from all points on the aperture.

Of course, you must perform the same calculation for each point on your viewing screen to determine the complete diffraction pattern - a time consuming task. In this experiment the approach will be more qualitative. You will use your knowledge of diffraction patterns formed by slits to understand the patterns formed by more complicated apertures.

- Optics bench
- Component holders (2)
- Diffraction plate
- Any colored filter
- pin
- Light source
- Variable aperture
- Black construction paper
- Slit mask

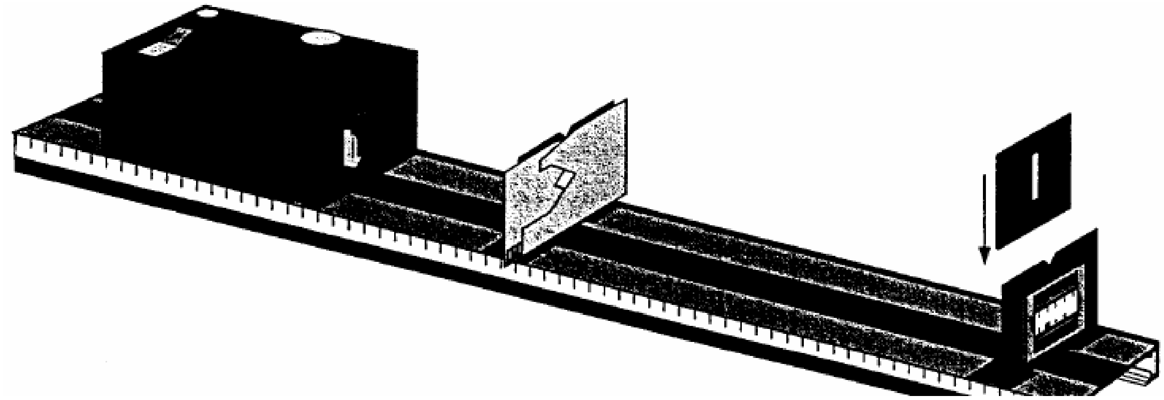


Figure 9 (Courtesy of PASCO)

Procedure

Setup as in Fig 9. Begin with the variable aperture fully open. Looking through the diffraction plate at the light source filament, examine the diffraction patterns formed by patterns H, I, and J.

While looking through pattern H, slowly close the variable aperture. Repeat this with patterns I and J.

1. What affect does aperture size have on the clarity of diffraction patterns?

2. What affect does aperture size have on the brightness of the diffraction patterns?

Adjust the variable aperture to maximize the brightness and clarity of the pattern. Place a color filter over the light source aperture.

3. In what way does the color filter simplify the diffraction patterns that are formed?

Crossed Slits

Examine the diffraction pattern formed by aperture H, the crossed slits. As you watch the pattern, slowly rotate the diffraction plate so first one slit is vertical, then the other.

1. Describe the diffraction pattern in terms of the patterns formed by each individual slit.

Random Array of Circular Apertures

Examine the diffraction pattern formed by aperture I, the random array of circular apertures. The pattern is similar to that formed by diffraction through a single circular aperture. To verify this, use a pin to poke a small hole in a piece of black construction paper. Look at the light source filament through this hole. In the pattern formed by the random array, the patterns from all the circular apertures are superposed, so the combined diffraction pattern is brighter.

In the random array, smaller circles are used than you can produce with a pin.

2. What affect does the smaller diameter of the circles have on the diffraction pattern?

In observing single slit diffraction, you found that the narrower the slit, the greater the separation between the fringes in the diffraction pattern. This is generally true. For any aperture, diffraction effects are most pronounced in a direction parallel with smallest dimension of the aperture.

3. Use the above generalization to explain the symmetry of the patter formed by a circular aperture.

Square Array of Circular Apertures

Examine the diffraction pattern formed by aperture J, the square array of circular apertures.

4. How is the pattern similar to that formed by the random array? How is it different?

Each circular aperture in the array forms a circular diffraction pattern with maxima and minima appearing at different radii. However, the regularity of the array causes there to be interference between the patterns formed by the individual circles. This is analogous to the way in which the double slit interference pattern creates maxima and minima that are superimposed on the single slit patterns created by the individual slits.

5. In your lab notebook on a new page, draw the diffraction pattern you would expect if there were no interference between the patterns from the different holes (as in the random array). Clearly indicate the minima and maxima.

6. To understand the interference that takes place, consider the array of points as if it were actually a collection of parallel slits, such as those shown in Figure 10 a, b, and c. Draw the diffraction patterns that would be created by each of these collections of parallel slits. Clearly label the maxima and minima.

7. Your drawing from step 5 shows where the light is diffracted to from each individual circular aperture. To approximate the effect of interference between circular apertures, superimpose a copy of one of your interference patterns from step 6 over your drawing from step 5. Only where maxima overlap will there be maxima in the combined pattern. Repeat this procedure for each of your interference drawings.

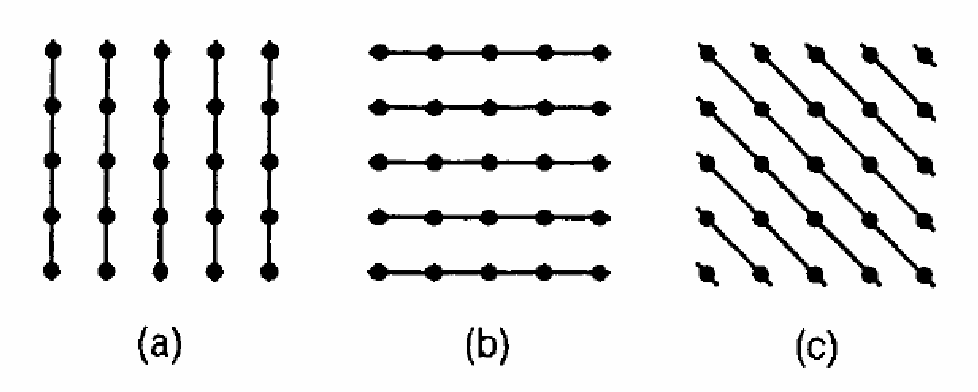


Figure 10 (Courtesy of PASCO)