Name: ____________________

Partner(s): ____________________

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Date: ____________________

Physical Optics II (more on *phase shifts*)

Background

Last time, we discussed the (topsy-turvy) fact that when light passes through a lens, a *smaller* focal spot results when a *larger* beam is incident upon the lens, as well as the fact that this phenomenon, like other basic laws of optics, is a result of **interference** between many different light rays (waves!). Practically, the upshot was that, in order to achieve the smallest spot size for high-resolution microscopy (or for a variety of clinical treatments), we need a large-diameter lens, in order to accept a large-diameter beam. The key result was that we now think of the transmitted light (as well as the nearby *dark* regions!) in terms of **interference**, a really fascinating phenomenon that we will systematically explore today, in the simplest cases we could think of.

Part 1: Double Slit

The experimental setup is the same as last time, shown in Figure 1. A monochromatic Helium-Neon laser, having a known wavelength of **λ = 632.8 nm**, is positioned on the short bench. The laser should be positioned such that it points to the center of the screen. Objects causing diffraction will be positioned just a few centimeters from the laser. To get the greatest resolution, the (measured) **distance between the object and the observing screen, *L*, should be as large as possible**.

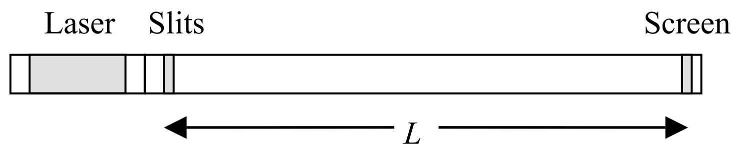


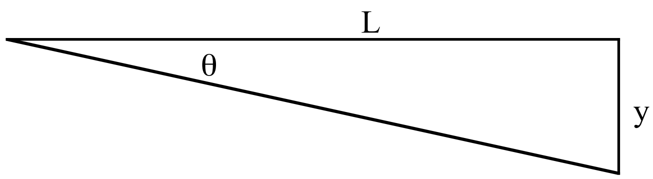
Figure 1

Today, instead of using a slide with the *single* slit aperture, you will examine what ensues when the laser is incident upon a slide containing a **pair** of very closely spaced slits (Slide 9165-B). Unlike last week, we will now measure the spacing between the **MAXIMA in the intensity** of the transmitted light.

Now that there are multiple slits, the spacing for the **MAXIMA** are given by Equation 1:

$$m\lambda = d\sin\theta \qquad (1)$$

where m is the number of the maxima: the intensity peak nearest the central bright spot (or "fringe") has m = 1, the second-nearest intensity peak is m = 2, and so on. Here, λ is the wavelength of the light diffracted, ***d* is the distance *BETWEEN* the slits**, θ is the angle from the slit to the measurement with respect to the location of the central fringe.



If the angle of diffraction, θ, is small, we can make a **small angle approximation**:

$$\sin\theta \approx \theta \approx \tan\theta = \frac{y}{L}$$

Figure 2

In the limit of small angles, Equation (1), predicts intensity ***MAXIMA*** at locations given by:

$$m\lambda = d\frac{y}{L} \quad \text{(\underline{Double}-Slit Intensity \underline{Maxima})} \quad (2)$$

Now, … before you start thinking that this is just what we did last time in lab, let's look a bit more carefully at what we saw when we had a *single* slit aperture. In that case, we had found that there would be ***MINIMA*** in the intensity at positions given by:

$$m\lambda = a\frac{y}{L} \quad \text{(\underline{Single}-Slit Intensity \underline{Minima})} \quad (3)$$

where ***a* is the width of the slit**.

Now, if you solve these equations for the expected locations, y, of these bright or dark spots, you see that there is a **reciprocal relationship** between y and d in Equation (2) and a similar **reciprocal relationship** between y and a in Equation (3). The upshot is that if $a \ll d$, then the single-slit minima will be much further from the optic axis than the spacing between the double-slit maxima. In that case, the intensity pattern we predict near the optic axis will be entirely determined by the interference between the two slits:

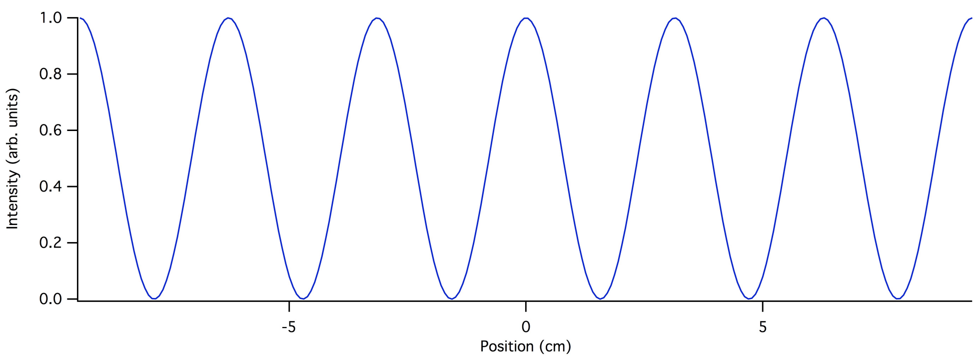


Fig. 3. The expected double-slit interference pattern, when $a \ll d$.

That is, the intensity pattern associated with diffraction from one very *narrow* SINGLE slit should have a *broad* central maximum, and over the central portion of that pattern, the intensity is pretty uniform. So, if we do have $a \ll d$, then near the optic axis the observed pattern is just due to interference *between* the two slits.

On the other hand, let's suppose value of the slit width, *a*, is *not* quite so very, very narrow compared to the spacing between slits, *d*. If we had only ONE of these slits, then (from last week) we expect the transmitted intensity profile to look like:

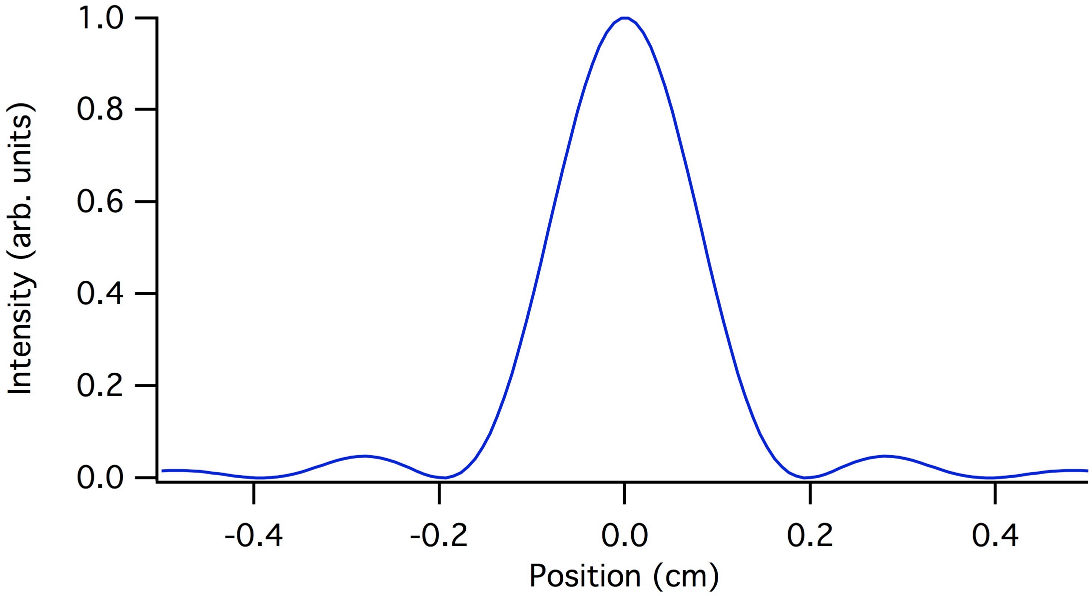


Fig. 4. A <u>single</u>-slit transmission pattern (as studied last time in lab).

Now, when there are TWO such slits, the central maximum will still contain the two-slit interference shown in Figure 3, but with an overall amplitude that is determined by the single-slit transmission shown in Figure 4.

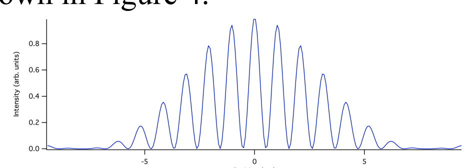


Fig. 5. In general, the amplitude of the <u>two-slit</u> interference pattern is determined by the single-slit transmission pattern.

In particular, note that if the single-slit diffraction pattern indicates that there will be <u>no</u> intensity at a particular point, as given by Equation (3), then that spot really will be dark *even if* Equation (2) shows that the waves coming from the two slits are *in phase* at that point. For this reason, some orders predicted by Equation (2) will appear to be "missing."

Procedure

From fitting your observations to the prediction given by Equation (2), you can extract an experimental measurement of your laser's wavelength:

Width of each slit, a = _____________

Spacing between slits, d = _____________

$L \pm dL$ = _______________

m	$y \pm dy$	$\lambda_{\text{experimental}}$	% error
1			
2			
3			

Part 2: Quadruple Slit

Before doing the experiment, qualitatively, what differences do you expect, in comparison to the double-slit aperture, as the number of slits increases? Please record your thoughts *before* proceeding:

Replace the slide with the double-slit aperture with a slide containing a quadruple-slit aperture (Slide 9165-C) and repeat the measurements made in the previous parts of this lab. From your sketches, record the relevant data in the table below:

No. of slits = ______________

Width of each slit, a = ______________

Spacing between slits, d = ______________

$L \pm dL$ = ______________

m	$y \pm dy$	$\lambda_{experimental}$	% error
1			
2			
3			

Part 3: Diffraction Grating

Let's now observe what happens when there are many, many, many slits. So that the beam might illuminate a very large number of slits, construct a beam expander by separating two lenses by the sum of their focal lengths (*e.g.*, using a -22-mm concave lens and a +252-mm convex lens).

Which lens should be closer to the laser? [Hint: a simple geometric "ray-optics" drawing may help you to decide.]

Be sure that you TEST that the output is "collimated" by using an index card: if the separation between lenses is too much, then the beam will shrink as you move the card further away; if the separation is too little, then the beam will expand.

Now replace the slide with the quadruple-slit aperture with a slide containing a diffraction grating (*e.g.*, Slide 9127), and examine what happens as you move your observing screen closer and closer to the laser.

For whatever L-value you decide is best for your measurements, sketch what you observe below. Be sure to include any relevant measurement values.

Is the small angle approximation still valid? If not, why?

Perform the appropriate calculation to determine the wavelength of the laser.

How do your previous results compare to this? **Is there an improved accuracy and/or precision when using the diffraction grating?** If so, ***why***?

Part 4: A two-dimensional diffraction pattern

Leave your beam expander in place. Replace the diffraction grating with the large "Aperture Mask" (Slide 9139), placed on the far side of your component carrier, and make sure that the opening is reasonably centered on the beam. On the *other* side of that same component carrier, place a **two-dimensional** slit pattern (slide 9165-D) and observe the diffraction pattern produced. The observed pattern can be recorded below.

Can you explain the observed pattern from what you have already done in this lab? The following hints may help.

- Light obeys the **principle of superposition**.
- The two-dimensional slit pattern is the **superposition** of a number of one-dimensional slit patterns.

Part 5: Hologram (*transmission type*)

So far today, we have introduced diffracting objects that have regions that are either completely opaque or completely transparent. We optical elements of this design "amplitude modulators." But you know that another sort of control is possible, namely "phase modulation." An element that is designed to control take advantage of this is typically called a hologram. A good deal of information can be encoded in this sort of (really very simple) device, as you will see.

Leave your beam expander in place. Replace the component carrier holding your diffraction grating with the rotation table and small component carrier, with the hologram mounted. Turn the rotation table so that the light strikes the hologram at an angle of around 30°.

CAUTION AN OBESERVER SHOULD NEVER PUT THEIR EYE DIRECLY IN LINE WITH THE LASER BEAM. USE CARE!

While viewing is optimal if your eye is in the same plane defined by the optic axis and the normal to the hologram surface, you must **not** ever move your eye onto the optic axis!

Once you can clearly see the image of a chess piece (some people prefer to use a diffuser), **keep your viewing angle fixed** and turn the rotation table (all the way through 180° of rotation) and note any change in the image:

Next, with the rotation table kept fixed at some angle you like, change your viewing angle (by moving the position of your head to different locations in the plane of interest), and note any difference in the perspective you observe.

Initiative

Possible ideas:

1. Discuss how you could use the procedures in used in this lab to determine the structure of, say, a gamma globulin molecule? or DNA? or crystals of crystallite? Could you use a 632.8 nm laser?
2. You can supplement the required measurements with additional measurements on sections of the supplied slides that you have not yet used.

Conclusions