INTERFERENCE AND SUPERCONDUCTIVITY

Printed Names:  

Signatures:

________________________________________  

________________________________________  

________________________________________  

________________________________________  

Date: ________________________________

Lab Section: __________________________  
Instructor: ____________________________

GRADE: ______________________________

PHYSICS DEPARTMENT
JAMES MADISON UNIVERSITY

Revision Spring 2002
PHYSICS 150
LAB INSTRUCTIONS

Interference and Superconductivity

Purpose: To explore some of the wave properties of light and to measure the resistance of a superconductor.

Equipment: Laser Source, Diverging Lens, Pin, Screen, Holders, Meter Stick, Lab Jack, Slides and Holder. Superconductivity demonstration equipment consisting of four point probes, small magnetic disks, liquid nitrogen, and standard multimeters, and Logger Pro program.

Background (light waves): The wave model of light, in contrast to ray model, explains diffraction and interference effects that result when a light beam is interrupted by the edge of an opaque object, a single opening, a double slit or a diffraction grating. It is important to realize that both models correctly predict the behavior of light but in separate regimes. Light exhibits its wave behavior when distances are comparable to the wavelength and the ray character when apertures are large.

The coherent light from a laser beam readily lends itself to a demonstration of the diffraction or interference pattern when projected onto a screen (Figure 1). The nature of the pattern will be a function of the source wavelength, \( \lambda \), the distance between object interrupting the beam and the screen, \( D \), and the characteristics of the object itself.

![Figure 1](image.png)

**Single Slit.** When the coherent beam is directed onto a single slit of width, \( w \), the resultant diffraction pattern on the screen a distance, \( D \), from the slit appears as seen in Figure. The width of the central maximum, \( x_c \) in the figure, is given by the formula:

**Equation 1.** \[ x_c = 2 \lambda D / w \]
**Double Slit.** When the coherent beam is directed onto a double slit, where separation between the two slits is given by s, the resultant pattern is a series of evenly spaced lines as pictured in figure. The spacing between adjacent lines, \( x_s \), is given by the approximation:

**Equation 2**

\[ x_s = \frac{\lambda D}{s}. \]

Alternatively, the wavelength may be expressed as

\[ X_s \]

**Equation 3**

\[ \lambda = (s)(\frac{x_s}{D}). \]

**Diffraction Grating.** When the coherent beam is directed onto a diffraction grating where many parallel lines are etched into a glass or plastic plate, the resultant pattern on the screen appears as a series of equally spaced dots. When the separation between adjacent grating lines is designated as d, the dot spacing, \( x_d \), is given by the approximation:

**Equation 4**

\[ x_d = \frac{\lambda D}{d}. \]

Alternatively, the wavelength may be expressed as

\[ X_d \]

**Equation 5**

\[ \lambda = (d)(\frac{x_d}{D}). \]

**Holography.** A holograph film, when illuminated by a coherent source will create a set of images viewed by an observer. Even when a portion of the holographic film is blocked out, it is still possible to see the complete set of images.

Note--Be sure to estimate and record measurement uncertainties for all data readings.

**Part I. Interference Pattern Formed in Pinhead Shadow.**

**A REMINDER--DO NOT LOOK DIRECTLY INTO THE LASER LIGHT SOURCE WHEN IT IS OPERATING OR AT ITS DIRECT REFLECTION FORM A MIRRORED SURFACE**

1. Turn the laser beam switch on and place the screen 1.00 m from the laser source and the diverging lens approximately 2 cm in front of the source (Figure 1). Adjust the lens' lateral and height positions so that the enlarged beam is centered on the screen.

2. Initially place the pin (in its holder on the lab jack) about 40 cm from the lens. The elevation
adjustment on the lab jack is to be used to position the pin head at just the proper height to center it within the laser beam. A shadow image of the pin head should appear on the screen. Gradually move the pin toward the lens until it is about 2 cm from the lens.

3. Observe the interference pattern around the edge of the pin shadow and take note of the difference when the pin is close to the lens compared to that when it is more distant. Check with the lab instructor to see if you have observed this effect. This is a demonstration that small obstacles and apertures can exhibit interesting patterns. We will explore this further in this lab.

Part II. Diffraction Pattern--Single Slit.

1. Remove the pin and diverging lens. Tape the graph paper to the screen surface. Place the single slit slide into a holder on the lab jack and position it about 5 cm from the laser source. Place the screen at 50 cm from the slide. Position the slide so that the beam hits one of the single slits.

2. Note the resultant interference pattern on the screen (see figure and formula Equation 1) and measure $x_c$, and the width of the bright central band and record this value in your data table with n error estimate.

3. Repeat the above steps with the beam directed through a different slit. From Equation 1 you may infer that the central maximum is inversely proportional to the slit width. Does a comparison of data from steps support this? Discuss in the analysis section.

Part III. Interference Pattern--Double Slit

In this part with some double slits one can see both the single slit and the double slit pattern. You may need to explore a bit to untangle the patterns.

1. Replace the single slit with the double slit slide. Again the slide should be about 5 cm from the source. Position the slide so that the beam is incident upon one of the double slits. Place the screen 100 cm from the slide. There should appear a pattern of alternating and equally spaced bright and dark regions (Equation 2, Equation 3 and figure). If you do not get this result, then carefully adjust the positioning of the slide; if this fails, check with the instructor.

2. Determine $x_s$, the average distance between the centers of two adjacent bright bands. Accordingly, measure the total distance, X, over a multiple number of band spacings, n, and then divide by n to obtain the value of $x_s$. Make sure you get n right. Record the values of X, n and $x_s$ in your data table.

3. Repeat steps 1 and 2 above with a different double slit. From Equation 2 you may infer that the image band spacing is inversely proportional to the slit separation. Does a comparison of
data from steps 2 and 3 support this? Discuss in the analysis section.

**Part IV. Multiple Slit Diffraction Grating**

1. Use the small mosaic slide with Metrologic on the bottom. Place this slide 5 cm from the source and again move the screen to the 100 cm position. Direct the laser beam through the 25/mm multiple slit grating. (With Metrologic on the bottom the three top squares are from left to right 25l/mm, 50l/mm and 100l/mm). Note 25l/mm is to be read as 25 lines per mm; this is equivalent to a spacing of $4.0 \times 10^{-2}$ mm, or $4.0 \times 10^{-5}$ m, between lines. A series of evenly spaced bright spots should appear on the screen.

2. Determine $x_d$, the distance between the centers of two adjacent spots, using the same technique as in Part III above. Record the values of D, n, X and $x_d$ in your data table.

3. Repeat steps 1 and 2 above using the 50/mm grating.

4. Repeat steps 1 and 2 above using the 100/mm grating. From Equation 4 and Equation 5 you may infer that the bright spot spacing is inversely proportional to grating spacing. Does your data from steps support this? Discuss in the analysis section.

5. Use the data from each of the steps 1-4 with Equation 5 to determine the value of $\lambda$ (in nm). Report these three calculated values with the data table. Do the three values appear to be the same, within limits of measurement uncertainty? Discuss in the analysis section.

6. Calculate an average of $\lambda$ from the three values determined in step 5. Report this result with the data table. Within limits of measurement uncertainty, does this average appear to be equal to the assumed value of 632.8 nm for the Helium Neon laser? Discuss in the analysis section.

**Part V. Holograms.**

**Additional Equipment:** Holograms have been set up for your viewing.

1. From a position on the side of the slide opposite the source, look into the hologram slide at a downward slanting angle. You should be able to see a group of chess pieces. Move your head back and forth from right to left and attempt to determine if you see a parallax shift as you do. Count the total number of pieces observed. Record this number in your data table.

2. Have your partner hold a piece of paper across the right half of the slide as you view the chess pieces. Again move your head back and forth and count the number of chess pieces that may yet be seen. Record this number in the data table. Make sure that all the partners in the lab group are given the opportunity to be the viewer.
SUPERCONDUCTIVITY

The resistance of a piece of superconducting material will be measured as a function of temperature by the entire class together. A copy of this data will then be analyzed by each group.

Superconductors have special electromagnetic properties:

1. Superconductors have NO electrical resistance. Once a current is produced in a superconducting ring it will persist for many years. The ring exhibits no resistance to DC currents, no heating and no losses.
2. Superconductors expel applied magnetic fields so that the field is zero everywhere inside the superconductor. This property is known as the Meissner effect.

The behavior of superconductors can not be explained by the principles of classical physics. One must introduce the ideas contained in quantum physics, the physics of atoms. The superconducting state is known to be a special quantum condensation of electrons.

The table shows a list of materials that have exhibited superconductivity. These characteristics, however, are only observed below a certain temperature $T_c$ and in a magnetic environment with a magnetic field smaller than $B_c$. When the critical temperature is measured in the presents of an applied magnetic field the value $T_c$ is reduced. These materials are type I superconductors and their use is limited by the limits imposed by $B_c$.

A second type of superconductor called type II has a much higher value of $B_c$. The ability to withstand higher B fields and remain superconducting permits the fabrication of superconducting magnets.

Notice that all of the materials listed in the table do not exhibit superconductivity unless the temperature is extremely low. Often liquid helium is used to reach and maintain these low temperatures. Helium becomes a liquid at standard pressure of 760 Torr at 4.2 K.

In 1987, a new superconducting material was discovered with a critical temperature of about 30 K. This discovery prompted an intense search for new superconducting materials and resulted

<table>
<thead>
<tr>
<th>Superconducting Material</th>
<th>$T_c$ (K, degrees Kelvin)</th>
<th>$B_c$ (Tesla)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>1.180</td>
<td>0.0105</td>
</tr>
<tr>
<td>Ga</td>
<td>1.083</td>
<td>0.0058</td>
</tr>
<tr>
<td>In</td>
<td>4.153</td>
<td>0.0411</td>
</tr>
<tr>
<td>Hg</td>
<td>3.408</td>
<td>0.0281</td>
</tr>
<tr>
<td>Pb</td>
<td>7.193</td>
<td>0.0803</td>
</tr>
<tr>
<td>Sn</td>
<td>3.772</td>
<td>0.0305</td>
</tr>
<tr>
<td>Ta</td>
<td>4.470</td>
<td>0.0829</td>
</tr>
<tr>
<td>Ti</td>
<td>0.390</td>
<td>0.0100</td>
</tr>
<tr>
<td>W</td>
<td>0.015</td>
<td>0.0001</td>
</tr>
<tr>
<td>Zn</td>
<td>0.830</td>
<td>0.0054</td>
</tr>
<tr>
<td>Type II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nb$_3$Sn</td>
<td>18.0</td>
<td>24.5</td>
</tr>
<tr>
<td>Nb$_3$Al</td>
<td>18.7</td>
<td>32.4</td>
</tr>
<tr>
<td>V$_3$Si</td>
<td>16.9</td>
<td>2.35</td>
</tr>
<tr>
<td>PbMoS</td>
<td>14.4</td>
<td>6.0</td>
</tr>
</tbody>
</table>
in a new class of superconductors called high temperature superconductors. In today’s lab we will explore the properties of YBa$_2$Cu$_3$O$_7$ a superconductor that has a critical temperature above 77 K, the boiling point of Nitrogen. Because liquid nitrogen is abundant and inexpensive, superconductors with critical temperatures above the nitrogen boiling point, open the door for many new applications. However, most of the new high temperature superconductors are ceramics and, as you will see when you examine the material, they offer a new set of challenges in terms of manufacturing wire.

**Part VI**

The apparatus for the measurement can be found in the front of the classroom. Your instructor will explain the setup (shown in figure) and control the performance of the experiment. The students will record the data.

There are three meters. One meter measures the voltage between points b and c. One meter measures the current between a and d. One meter measures the voltage across a thermocouple. This voltage will be converted into a temperature using a conversion chart.

First record the meter readings when everything is at room temperature. The instructor will cool the superconductor with liquid nitrogen. After the system has stabilized record the meter readings at liquid nitrogen temperature. The instructor will remove the liquid nitrogen so that the system warms up slowly. The data points at the beginning of the warm up period are very important. Students should devise a method to record the data efficiently and insure that enough points are...
recorded. You can run through the process as many times as needed.

Convert the voltage measurement for the thermocouple by extrapolating from the table provided. Create a new excel worksheet and enter these extrapolated temperatures and the corresponding values for voltage across the superconductor, Vbc, and the current through the superconductor. Calculate the resistance. Plot R vs T for the experiment. Comment on what you found.

If time allows a similar measurement can be made on a non-superconducting metal for comparison. Record the resistance vs temperature dependence and plot the resulting data on the same plot as for the superconductor. Comment on the difference.
<table>
<thead>
<tr>
<th>Observe the pattern of laser &amp; pin.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single slit measure x and compare (2 slits).</td>
</tr>
<tr>
<td>Double slits record and compare (2 double slits)</td>
</tr>
<tr>
<td>Grating 3 gratings.</td>
</tr>
<tr>
<td>Calculate wavelength based on grating data.</td>
</tr>
<tr>
<td>Observe holgram.</td>
</tr>
<tr>
<td>Plot R vs t for superconductor.</td>
</tr>
</tbody>
</table>