Penn State RET in Interdisciplinary Materials

Teacher's Preparatory Guide

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Single-Slit and Double-Slit Diffraction

Purpose This lab is designed to help students understand the concepts behind Young's double slit experiment.

Objectives
- The student will measure the wavelength of light emitted by a hand-held laser
- The student will observe double-slit diffraction.
- The student will observe single-slit diffraction.

Time required One class period (90 minutes)

Level High school

National Science Education Standards [Grade 12]
Content Standard C
- C.5.a.8 Wave theory, sound, light, the electromagnetic spectrum and optics
- C.5.a.10 Fundamental processes of investigating in physics
- C.5.b.17 Light behavior, including wave-particle duality and models
- C.5.a.21 How to design, conduct, and report research in physics

Teacher Background

The academic material for this lab comes directly out of the textbook. Double-slit diffraction is covered in Section 4.4, and single-slit diffraction is covered in section 9.2. Recommend building your own slit cards beforehand to show students what their product should look like. The equations of interest include $\theta=\lambda/b$ for single-slit diffraction and $s=\lambda D/d$ for double-slit diffraction.

Materials
- 3x5 cards
- Tape
- Scissors
- X-ACTO knife
- Thin electrical wire
- Measuring devices (calipers, ruler, measuring tape).
- Laser pen

Advance Preparation

- 3x5 cards should be a common office supply.
- Tape should be a common office supply.
- Scissors should be a common office supply.
- X-ACTO knives can be found on Amazon for under $5.
- Thin electrical wire should be a common supply in your physics lab. If not, 18 gauge (1.1 mm) can be found on Amazon for $10-$15.
- Measuring devices (calipers, ruler, measuring tape) should be a common supply in your physics lab.
- Laser pens can be found on Amazon for as little as two for $8.

Safety Information

- Although we are using very low-powered lasers meant for home use, it is never a good idea to look directly into a laser.
- Use caution with the X-ACTO knives. They are sharp.

Teaching Strategies

This lab exercise is best conducted in groups of two or three, although it could be done individually.

Prior to the lab, students need to have basic knowledge of what the double-slit experiments are, why the diffraction patterns occur, and the basic equations involved. A wave demonstration in a ripple tank would be a good start. As with earlier topics, basic math to include trigonometry is assumed.

Resources: You may wish to use these resources either as background or as a resource for students to use in their inquiry-based design.

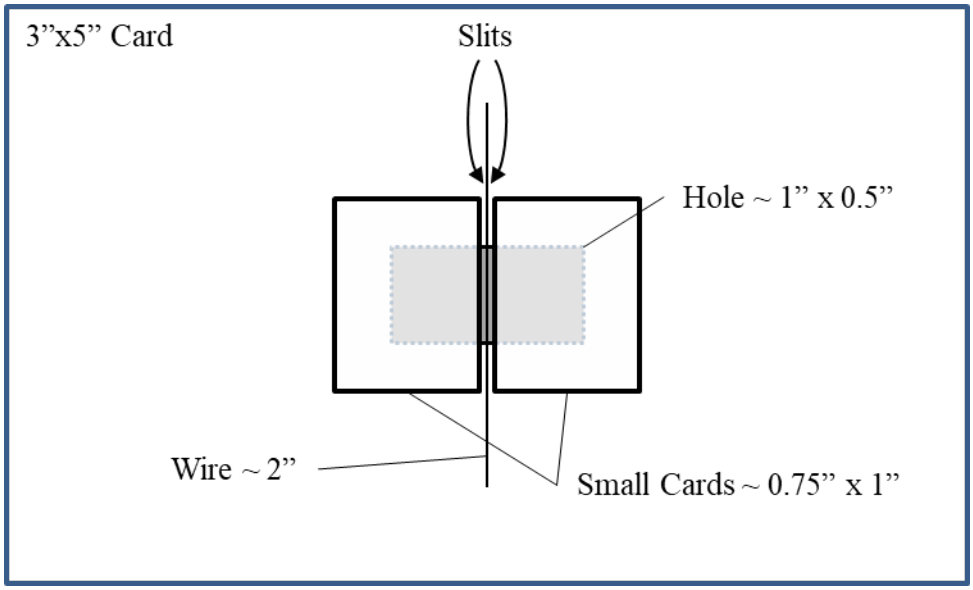
- *IBDP Physics HL* by Kognity found at https://www.kognity.com/, sections 4.4, 9.2, 9.3
- *Physics for the IB Diploma* by K.A. Tsokos, sections 4.4, 9.2, 9.3
- Khan Academy has a series on electromagnetic waves and interference found at: https://www.khanacademy.org/science/physics/light-waves
- From the University of Colorado: https://www.colorado.edu/physics/phys2020/phys2020LabMan2000/2020labhtml/Lab5html/lab5.html
- PhET Simulation from University of Colorado Boulder https://phet.colorado.edu/en/simulation/legacy/quantum-wave-interference

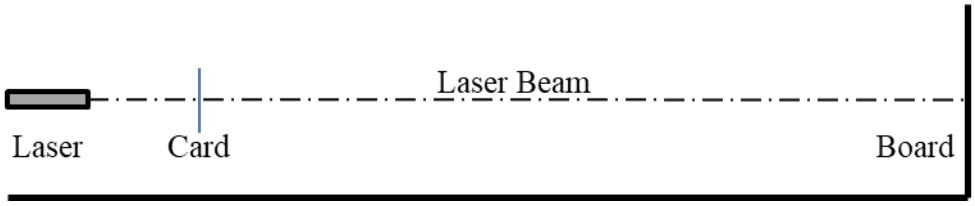
Directions for the activities

- Class prior, announce the objectives of the lab.
- Explanation of the lab should take 5-10 minutes.
- Construction of the cards should take 15-20 minutes.
- Data collection should take 25-30 minutes
- Basic computations should take 15-20 minutes
- Clean=up should take 5-10 minutes
- Formal write-up should be done at home due in two class periods

Procedure for Double-Slit Experiment

1. With an X_ACTO knife and a ruler, cut a small rectangle out of a 3x5 card
2. Strip a short, thin-diameter wire
3. If the gauge of the wire is not known, measure the diameter with calipers
4. Tape the wire in place over the hole cut in the 3x5 card
5. Cut two small rectangles and tape on either side of the wire, making two thin slit
6. Measure with the tape measure a distance from the white board (or from a white piece of paper taped to the wall)
7. Holding the 3x5 card at that distance, shine the laser through the hole in the 3x5 card and landing on the board/paper
8. While shining the laser, observe the diffraction pattern and measure the distance between maxima





Procedure for Single-Slit Experiment

This is a chance for the students to try things out themselves. Conducting a single slit experiment at the high school level is not a trivial task. The may need to shoot the laser clear across the room, and they may need to turn the light off to see the projection better. This may be an example of a lab that they just do not figure out with the materials available, but that in itself is also a learning experience.

Cleanup Return all non-disposable materials (laser pens, scissors, X-ACTO knives, measuring devices) to the teacher's desk.

Single-Slit and Double-Slit Diffraction

Introduction

Is light a particle or a wave? That was the question plaguing scientists like Newton, Grimaldi, and Huygens in the 1600s. In 1817, Thomas Young proved without a doubt that light can be explained as a wave through this very experiment.

Materials

- 3x5 card
- Tape
- Scissors
- X-ACTO knife
- Electrical wire
- calipers
- Ruler
- Tape measure
- pencil
- calculator

Make a Prediction

Procedure for Double-Slit Experiment

9. With an X_ACTO knife and a ruler, cut a small rectangle out of a 3x5 card
10. Strip a short, thin-diameter wire
11. If the gauge of the wire is not known, measure the diameter with calipers
12. Tape the wire in place over the hole cut in the 3x5 card
13. Cut two small rectangles and tape on either side of the wire, making two thin slit
14. Measure with the tape measure a distance from the white board (or from a white piece of paper taped to the wall)
15. Holding the 3x5 card at that distance, shine the laser through the hole in the 3x5 card and landing on the board/paper
16. While shining the laser, observe the diffraction pattern and measure the distance between maxima

Procedure for Single-Slit Experiment

Now it is your turn. See if you can come up with a method to observe single-slit interference patterns. List your steps below:

Record Your Observations

Double-slit Experiment

Measurement	Variable	Value	Error (±)
Distance between the slit	**d (mm)**		
Distance to board	**D (m)**		
Distance from central max to next max	**s (mm)**		

Single-slit Experiment

Measurement	Variable	Value	Error (±)
Slit width	**b (mm)**		
Distance to board	**D (m)**		
Distance from central max to first min	**x (mm)**		

Analyze the Results

Double-slit diffraction $s=\lambda D/d$

Single-slit diffraction $\theta=\lambda/b$

Remember unit conversions

Double-slit Experiment

Computed Characteristic	Variable	Value	Error (±)
Wavelength	**λ (nm)**		

Single-slit Experiment

Computed Characteristic	Variable	Value	Error (±)
Angle from central max to first min	**θ (radians)**		
Wavelength	**λ (nm)**		

Show Calculations Below:

Draw Conclusions

1. What is the wavelength of the laser?

2. What is the uncertainty of your answer?

3. What color is the laser? Does this match the frequency range you gave in questions 1 and 2?

Enhancing understanding Cover this section *after* the activity.

For 150 years, scientists argued vehemently about whether light is a wave or a particle is. This experiment effectively ended the discussion, until Albert Einstein published a paper in 1905 describing light as a stream of particles, or photons, called the photoelectric effect.

So, how can light be a wave and a particle?

Going Further

What would happen to the if we change the size of the slits? The separation of the slits? The distance to the board?

If we take everyone's results and average them together, what is our consolidated result? How does it compare with the expected wavelength from the visible spectrum? Should we be more or less confident from averaged results?

Assessment and rubrics:

Lab Report:

- **Title and Abstract (15 Points)** Title, your first and last name, your partners' first and last name-5 points Abstract-10 points. The abstract is a paragraph briefly summarizing the objective, the procedures, and your results. An abstract is usually considered a brief overview of the entire investigation.
- **Objective (5 Points)** The objective is the beginning of the second page. The objective is a statement, which describes the question you are investigating. There may be multiple objectives. Please state them all.
- **Hypothesis (5 Points)** The hypothesis is a statement of what you expect for results. Obviously this should be done before the lab is performed. It is of little consequence whether your hypothesis is supported as a result of the investigation. It is not about, "guessing right." However, the importance of the hypothesis is to make you think ahead and make an educated prediction based on previous knowledge. The hypothesis is not a guess; it is in fact a prediction formed by logic. Therefore, you must include your reasoning in any hypothesis. In fact many investigations are centered on testing the logic behind the hypothesis. In many cases, the hypothesis may be stated as multiple "if…then…" statements.
- **Procedure (10 Points)** This section begins with the materials needed to perform the investigation. This section includes a numbered list of steps describing how the investigation was done. This section should be concise, yet detailed enough so that any interested party could repeat the investigation on their own and obtain identical results. Three points extra credit may be earned for including a detailed, labeled diagram of the apparatus.
- **Data and Observations (20 Points)** This section should be dedicated to data only (which includes observations). Please note that observations are not judgmental. You are not analyzing, drawing inferences, or conclusions. This section should be as factual as possible. This section may include: tables, labeled graphs, and calculations. Include a title and caption for all tables and graphs. Make sure units are included with all data and calculations.
- **Data Analysis (20 Points)** This section is one of the most important. Data analysis is where you discuss the meaning behind your data at length. What do the data tell you? What do our graphs indicate? What do your observations suggest? It is in this section when you revisit the objective of the investigation and determine in what ways your data answers your question. You must refer to data specifically and create an argument, which supports or disproves your hypothesis. However, don't be caught saying something that your data does not support! To aid you in topics to discuss in your data analysis, there may be specific analysis questions that I will give you. If I do give you additional analysis questions, be sure that they are addressed in this section.
- **Conclusion (20 Points)** A well-written conclusion is relatively brief. It is an overview of your results. Where the data analysis is an at length discussion of data and what is suggests, this section is focusing your analysis to a brief statement of conclusion. This should bring closure to your report. A conclusion should briefly answer all objectives, briefly refer to data, state if the hypothesis was supported or disproved, and briefly refer to how the results can be applied to other contexts (relate it to the real world).
- **Error Analysis (5 Points)** In this section, discuss all of the possible errors and limitations in your lab. It is here where you might describe reasons for not trusting your data. Examples could be discussing that there were not enough trials, friction was not accounted for, lack of calibration, or even the possibility of malfunctioning equipment. In addition, discuss how you would design the investigation differently if you were to conduct it again.