E&M Laboratory 1106, Summer 2025

Prof. D. Balakishiyeva, Prof. R. Guarino

https://www.physics.smu.edu/tneumann/110X_Summer2025/

Lab 12 — Young's Double Slit Experiment

Max. points: 54

Light, the electromagnetic radiation we perceive as vision, exhibits a fascinating and sometimes counter-intuitive characteristic known as wave-particle duality. In some phenomena, like the photoelectric effect, light behaves as if composed of discrete energy packets called photons, interacting much like particles. However, in other situations, light clearly demonstrates wave-like properties, such as diffraction and interference.

Thomas Young's double-slit experiment, first performed in the early 19th century, provided compelling evidence for the wave nature of light, challenging the purely corpuscular theories prevalent at the time. The core idea relies on the principle of superposition: when waves from two coherent sources overlap in space, their amplitudes combine. This combination leads to interference – regions where the waves reinforce each other (constructive interference, resulting in bright fringes) and regions where they cancel each other out (destructive interference, resulting in dark fringes). This pattern of alternating bright and dark bands is a hallmark of wave behavior and cannot be easily explained if light consisted solely of classical particles traveling in straight lines.

In this laboratory exercise, you will perform a version of Young's classic experiment using a modern laser as a coherent light source. Passing the laser beam through a pair of narrow, closely spaced slits produces an interference pattern on a screen, demonstrating the phenomenon of interference. You will analyze the positions and spacing of these interference fringes to quantitatively explore the wave properties of light and verify the relationships between the light's wavelength, the slit separation, and the geometry of the observed pattern. This experiment remains a fundamental demonstration of wave mechanics and the intriguing nature of light.

Your preparation: Work through before coming to the lab

- Prepare for the lab by thoroughly reading this worksheet, focusing on the measurement and analysis procedures. Understand the concepts behind Young's Double Slit experiment. Photos of the equipment (Optical Bench, Laser, Slit Holder, Light Sensor, Capstone Interface) and further introductory material will be available on the course website: https://www.physics.smu.edu/tneumann/110X_Summer2025/schedule-em/.
- Note any questions you have and ask your instructor at the beginning of the lab.
- Review the following topics in Halliday, Resnick, and Walker [1] (likely Chapter 35):
  - **Wave Nature of Light:** Huygens' principle, wave propagation.
  - **Coherence:** Meaning and importance for interference; why lasers are used.

- **Superposition and Interference:** Principle of superposition; conditions for constructive ($n\lambda$) and destructive ($(n+1/2)\lambda$) interference based on path difference.
- **Young's Double Slit Experiment:** Setup geometry (slit separation d, screen distance L); derivation of path difference $\Delta r = d\sin\theta$.
- **Fringe Location Formulas:** Relation between angle θ and bright/dark fringes ($d\sin\theta = n\lambda$, $d\sin\theta = (n+1/2)\lambda$).
- **Small Angle Approximation:** Validity and use ($\sin\theta \approx \tan\theta \approx y/L$) to find fringe positions y on the screen ($y_{\text{bright}} \approx Ln\lambda/d$, $y_{\text{dark}} \approx L(n+1/2)\lambda/d$).
- **Parameter Dependence:** How fringe spacing ($\Delta y \approx L\lambda/d$) changes with λ, d, and L.

Pre-lab: Upload to Canvas before coming to the lab

A reminder: Upload your answers as a PDF to Canvas before the lab begins (uploads close 30 minutes prior).

Pre-lab 1 7 points

1. (1 point) Define wave interference. Explain the conditions for constructive and destructive interference using the path difference (Δr) between two waves, expressed in terms of wavelength λ and integer n.
2. (1 point) Draw a diagram of the Young's Double Slit setup. Label: light source, slits (separation d), screen (distance L), a point P on the screen (distance y from center), and the angle θ.
3. (1 point) Derive the path difference Δr between waves reaching point P from the two slits, in terms of d and θ. State any approximations used.
4. (1 point) State the conditions for (a) constructive interference (bright fringes) and (b) destructive interference (dark fringes) at point P, using d, λ, θ, and integer n.
5. (1 point) Use the small angle approximation ($\sin\theta \approx y/L$) to find the approximate positions y on the screen for (a) bright fringes and (b) dark fringes, in terms of L, λ, d, and n.
6. (1 point) What is coherent light? Why is it necessary for observing a clear, stable interference pattern in this experiment?
7. (1 point) How does the spacing between adjacent bright fringes (Δy) change if: (a) slit separation d increases? (b) wavelength λ decreases (e.g., red to green light)? (c) screen distance L increases? Briefly justify each prediction using the formula from question 5.

Lab measurements and report: submission by end of class

A reminder: Document all measurements fully. Upload your final report (PDF with embedded plots/tables) to Canvas *by the end of class* (uploads close 10 minutes after). Submit your work even if incomplete.

Measurement 1 *Setup and Initial Observations* 3 points

This first section guides you through setting up the optical components and making initial observations of the interference pattern.

Equipment: Optical bench, red and green lasers, slits holder, light sensor with translation stage, Capstone interface.

1. **Position Components:** Place the laser and the slits holder near one end of the optical bench (low position readings). Position the light sensor assembly near the other end, ensuring the sensor's aperture faces the slits holder.
2. **Set Slit-Sensor Distance:** Adjust the distance L between the front face of the slits holder and the light sensor aperture to be approximately 1 meter. Carefully measure and record this actual distance L with its uncertainty. (Note: The slit plane itself is located 21.50 ± 0.05 mm from the holder's center indicator mark; the sensor aperture is near the front face of its assembly. Record the bench positions of the holder and sensor used to determine L.)
3. **Select Laser:** Begin with the red laser. Record its nominal wavelength (λ_{red}) specified on the laser. **Safety Warning: Never look directly into the laser beam.**
4. **Select Slits:** Familiarize yourself with the slits holder. Identify how to select different patterns and read their parameters (slit width a, slit separation d). Select the double-slit pattern specified as $a = 0.04$ mm and $d = 0.25$ mm. Record these values a and d.
5. **Configure Sensor:** On the back of the light sensor, set the aperture slit width to 0.1 mm. Turn on the sensor and connect it to the Capstone interface.
6. (1 point) **Observe Pattern:** Turn on the laser. You should see the interference pattern projected onto the white strip of the light sensor. Make a qualitative sketch or write a brief description of the pattern you observe (e.g., alternating bright and dark bands, relative spacing).
7. (2 points) **Record Setup Parameters:** Create a table in your lab notes or spreadsheet to record the essential parameters of your setup: Measured distance L (with uncertainty), λ_{red}, slit width a, and slit separation d.

Measurement 2 *Data Acquisition with Red Laser* 11 points

Now, you will systematically measure the intensity profile of the interference pattern for different slit separations using the red laser.

Equipment: As above, Capstone software.

1. **Configure Capstone:** Set up the Capstone software to record Light Intensity versus the Position reported by the light sensor's translation stage.
2. **Position Sensor:** Before each scan, manually move the sensor (using the translation stage handle) so that its aperture is positioned just to one side of the visible interference pattern.

3. **Scan Pattern:** Start data recording in Capstone. Slowly and steadily turn the handle to move the sensor across the entire interference pattern. Ensure you capture the central maximum and several fringes clearly on both sides. Stop recording once you have moved well past the main part of the pattern.

4. (3 points) **Dataset 1 (Red, d=0.125mm):** Change the slit setting on the holder to $a = 0.04$ mm, $d = 0.125$ mm. Record the new value of d. Repeat the positioning (step 2) and scanning (step 3) procedure. Save or export this intensity vs. position data with a descriptive name (e.g., "Red_d0125.csv").

5. (3 points) **Dataset 2 (Red, d=0.25mm):** Change the slit setting back to $a = 0.04$ mm, $d = 0.25$ mm. Record d. Repeat steps 2-3. Save/export this data (e.g., "Red_d0250.csv").

6. (3 points) **Dataset 3 (Red, d=0.5mm):** Change the slit setting to $a = 0.04$ mm, $d = 0.50$ mm. Record d. Repeat steps 2-3. Save/export this data (e.g., "Red_d0500.csv").

7. (2 points) **Dataset 4 (Red, 5-Slit Grating):** Select a 5-slit grating pattern (record its parameters, e.g., slit spacing, if available). Repeat steps 2-3. Save/export this data (e.g., "Red_5Slit.csv"). Briefly note any qualitative differences you observe in the pattern compared to the double-slit patterns.

Measurement 3 *Data Acquisition with Green Laser* 11 points

Next, you will repeat the measurements using the green laser to investigate the effect of wavelength.

Equipment: As above, switch to the green laser.

1. **Change Laser:** Carefully replace the red laser with the green laser. Record its nominal wavelength (λ_{green}). Ensure the distance L remains unchanged.

2. (3 points) **Dataset 5 (Green, d=0.125mm):** Select the slit setting $a = 0.04$ mm, $d = 0.125$ mm. Record d and λ_{green}. Acquire and save the intensity vs. position data as before (e.g., "Green_d0125.csv").

3. (3 points) **Dataset 6 (Green, d=0.25mm):** Select the slit setting $a = 0.04$ mm, $d = 0.25$ mm. Record d. Acquire and save the data (e.g., "Green_d0250.csv").

4. (3 points) **Dataset 7 (Green, d=0.5mm):** Select the slit setting $a = 0.04$ mm, $d = 0.50$ mm. Record d. Acquire and save the data (e.g., "Green_d0500.csv").

5. (2 points) **Dataset 8 (Green, 5-Slit Grating):** Select the same 5-slit grating pattern used with the red laser. Acquire and save the data (e.g., "Green_5Slit.csv").

Analysis 1 *Data Analysis and Interpretation* 22 points

In this section, you will analyze the collected data to determine the fringe positions, compare them with theoretical predictions, and discuss the results. The primary focus for detailed quantitative analysis will be on the datasets collected with the $d = 0.25$ mm slits for both red and green lasers.

- Dataset 2: Red Laser (λ_{red}), $d = 0.25$ mm

- Dataset 6: Green Laser (λ_{green}), $d = 0.25$ mm

You will use the other datasets for qualitative comparisons later.

1. **Data Preparation and Fringe Identification:** The first step is to process your raw data to accurately determine the positions of the interference fringes.

   (a) (2 points) **Process Dataset 2 (Red, d=0.25mm):** Load this dataset into Capstone or spreadsheet software. Create a plot of Light Intensity versus Position (y). Carefully identify the position of the central bright fringe (the peak with the highest intensity). Define this position as the origin ($y = 0$). Adjust all other position values by subtracting this central position, so your positions are now relative to the center of the pattern.

   (b) (3 points) **Identify Fringe Positions (Dataset 2):** Using your plot and/or data table, locate and record the positions (y_{measured}) of the first few bright fringes (intensity maxima) on either side of the center. Assign them integer orders $n = \pm 1, \pm 2, \dots$. Also, locate and record the positions (y_{measured}) of the first few dark fringes (intensity minima) on either side. Assign them half-integer orders corresponding to their location between maxima (e.g., the minimum between $n = 0$ and $n = 1$ corresponds to $n = 0$ in the formula $y_{\text{dark},n} = L(n+1/2)\lambda/d$). Create a table summarizing these findings for Dataset 2, listing the fringe order (n for bright, $n + 1/2$ for dark) and the corresponding measured position y_{measured}. Estimate and record the uncertainty associated with reading these positions from your graph or data.

   (c) (2 points) **Process Dataset 6 (Green, d=0.25mm):** Repeat the processing steps (a) and (b) for this dataset. Create a similar table summarizing the fringe orders and measured positions y_{measured} for the green laser data.

2. **Theoretical Fringe Position Calculation:** Next, calculate the expected fringe positions based on the wave theory of light and your experimental parameters.

   (a) (2 points) **Calculate for Dataset 2:** Using your measured screen distance L, the nominal wavelength λ_{red}, and the slit separation $d = 0.25$ mm, calculate the theoretical positions for the bright fringes ($y_{\text{bright},n} = Ln\lambda/d$) and dark fringes ($y_{\text{dark},n} = L(n + 1/2)\lambda/d$) corresponding to the same fringe orders (n) you identified experimentally in step 1(b). Add these calculated values ($y_{\text{calculated}}$) as a new column to your table for Dataset 2. Clearly show at least one sample calculation for a bright fringe and one for a dark fringe in your report.

   (b) (2 points) **Calculate for Dataset 6:** Repeat the calculation process from step (a) for Dataset 6, this time using the nominal wavelength λ_{green}. Add the calculated positions ($y_{\text{calculated}}$) to your table for Dataset 6.

3. **Comparison and Discussion (d=0.25mm Datasets):** Now, compare your experimental results with the theoretical predictions.

   (a) (2 points) **Quantitative Comparison:** For both Dataset 2 (Red) and Dataset 6 (Green), compare the measured fringe positions (y_{measured}) directly with the calculated theoretical positions ($y_{\text{calculated}}$) in your tables. To quantify the agreement, calculate the percentage difference between measured and calculated values for a few corresponding fringes (e.g., for the $n = 1$ and $n = 2$ bright fringes on one side).

(b) (2 points) **Agreement Discussion:** Discuss how well your measurements agree with the theoretical predictions based on the wave model. Are the observed differences generally within the range of your estimated measurement uncertainties (from step 1b and uncertainty in L)?

(c) (2 points) **Sources of Error:** Identify and discuss potential sources of experimental error, both systematic and random. Consider factors such as: uncertainty in measuring the slit-screen distance L; uncertainty in the nominal values of the laser wavelength λ and slit separation d; limitations in accurately reading the fringe positions from the intensity graph; potential misalignment of the laser, slits, and sensor; and the validity of the small angle approximation for the fringes you measured (is $\sin\theta \approx y/L$ a good approximation?).

4. **Qualitative Analysis (Effect of d and λ):** Use your other datasets to explore how changing the slit separation and wavelength affects the interference pattern.

   (a) (2 points) **Effect of Slit Separation (d):** Examine your plots or data tables for the red laser datasets where d was varied (Datasets 1, 2, 3 with $d = 0.125$ mm, 0.25 mm, 0.50 mm). Qualitatively describe how the observed spacing between adjacent bright fringes changes as the slit separation d increases. Does this observed trend agree with the theoretical relationship $\Delta y \approx L\lambda/d$? Explain your reasoning.

   (b) (2 points) **Effect of Wavelength (λ):** Compare the results for the red laser (Dataset 2, $d = 0.25$ mm) and the green laser (Dataset 6, $d = 0.25$ mm). Qualitatively describe how the observed fringe spacing changes when the wavelength λ is decreased (recall green light has a shorter wavelength than red light). Does this observed trend agree with the theoretical relationship $\Delta y \approx L\lambda/d$? Explain.

5. **Grating Observation (Qualitative):** Briefly reflect on the pattern produced by the 5-slit grating.

   (a) (1 point) Based on your observations of Datasets 4 and 8, describe the main visual differences between the interference pattern produced by the 5-slit grating and the patterns produced by the double slits. Consider aspects like the sharpness of the bright fringes, their relative brightness, and their spacing. (No calculations are required here).

References

[1] D. Halliday, R. Resnick, and J. Walker. *Fundamentals of Physics*. Fundamentals of Physics. John Wiley & Sons.