DRAFT HEISENBERG'S LASER DRAFT
SHORT TEACHER NOTES

LEARNING OBJECTIVES
Students be able to:
1. Demonstrate diffraction of light from a laser beam passing through a thin slit.
2. Show how changing the width of the slit changes the diffraction pattern.
3. Apply the deBroglie wavelength equation and experimental results to empirically demonstrate the relationship between uncertainty in position and uncertainty in momentum.

PRIOR KNOWLEDGE
Students must be able to:
- Plot and interpret a graph from data.
- Read and adjust a vernier caliper.
- Apply the rules for diffraction.

RESOURCES
What Heisenberg Knew from QuarkNet Data Activities portfolio

MATERIALS
Data Images or
- Two Vernier Calipers that can be adjusted and read to mm precision
- Red laser, low intensity, with a known operating wavelength.
- Meter stick or similar length-measuring device
- White or light-colored screen (e.g. poster board)
- Stands and clamps to fix all items into place
- Room with sufficient space which can be darkened.

IMPLEMENTATION
Figure 1 shows the experiment as performed at Notre Dame. There are approaches to this activity. The first is to take the data from the Data Images pages, calculate values of Δp and Δx, and then plot the results. The second is similar but for the class to replicate the experiment and generate their own data. In the latter case, *special care must be taken to train students in eye safety when using lasers*.

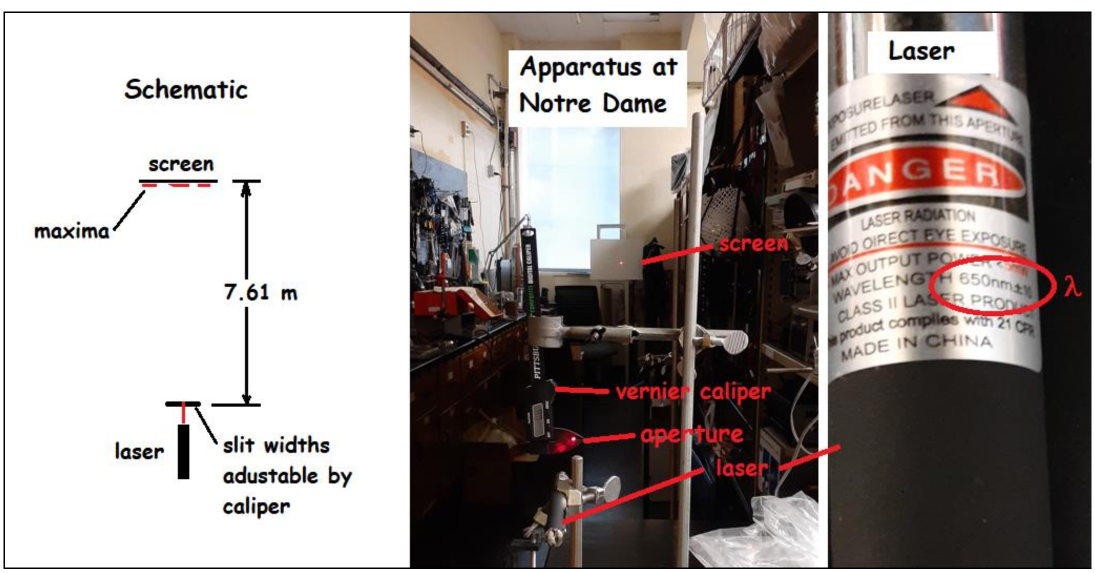


Figure 1. Experiment at Notre Dame.

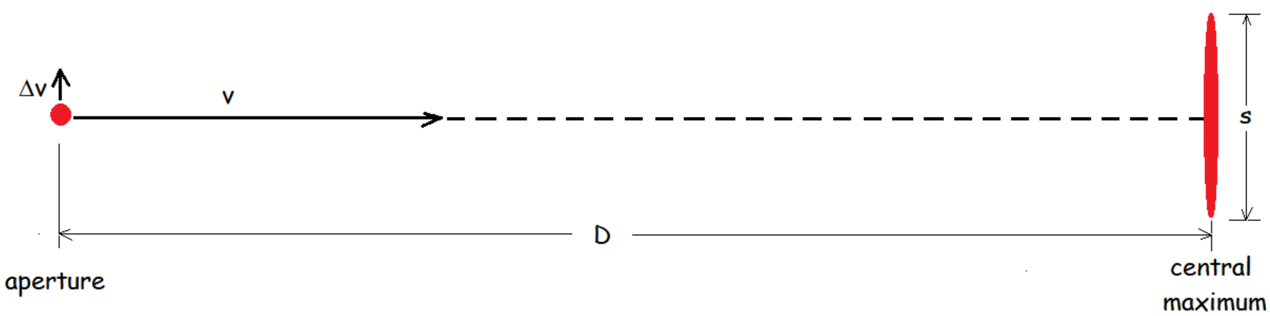
In either case, these are the steps to perform the experiment and analyze results:

1. Using stands and clamps place the laser in a horizontal position to send the beam some distance on the order of meters.
2. Set up the caliper of that the plane of its slit opening is at right angles to the beam.
3. Place the white or light-colored screen multiple meters away from the caliper with its plane vertical. Fix it in position.
4. Adjust the caliper to 0.1 mm slit opening.
5. Turn on the laser and adjust its position relative to the slit until you get a diffraction pattern on the screen.
6. Using a different caliper, measure the width of the central maximum and record it.
7. Repeat steps 4-6 multiple times, different slit opening widths up to 1 mm. If using the Data Images, students can read the caliper in the pictures.

After these steps are complete, students must determine Δp from the width of the central maximum and Δx from the size of the slit opening for each data point. It is preferable that Δp is calculated directly by students.

How to find Δp and Δx

It is not hard to get Δx: it is just the width of the aperture for the laser beam made by the vernier caliper at the source. Students can read it and record it. Finding Δp is a little more involved.

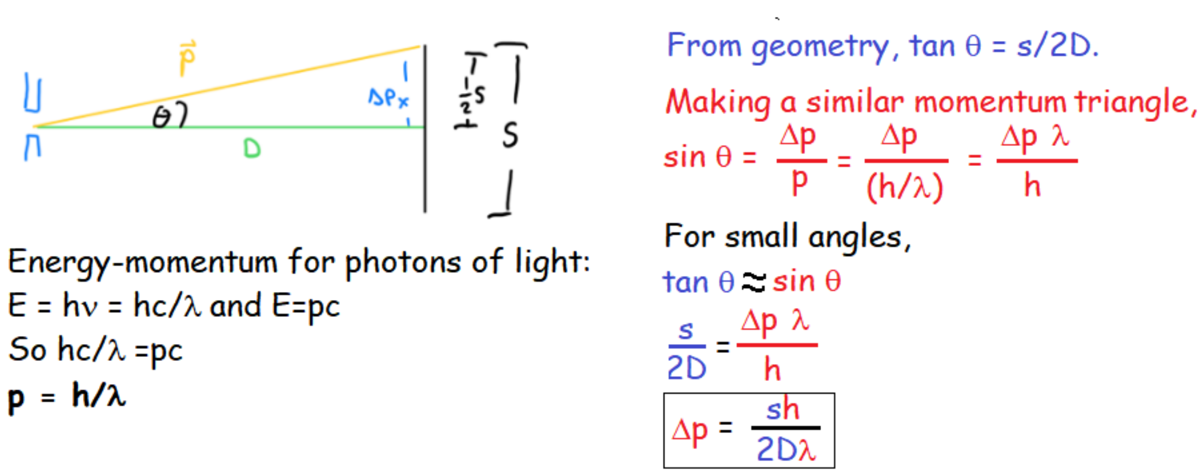


Here is an equation to calculate the uncertainty in momentum Δp from Planck's Constant h, the width of the central maximum s, the distance to the screen D, and wavelength of the laser light λ:

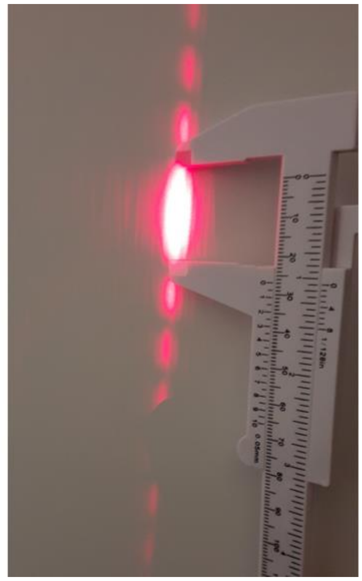
Δp = hs/2λD.

Students can use this equation to find Δp for each measurement.

Here is a derivation using similar values of sin and tan for very small angles:



Sample calculation
Let's make a sample calculation for an aperature 0.2 mm and width of central maximum s = 27 mm. The wavelength of the laser light is 650 nm and the distance from the aperature to the screen is 7.61 m. See below.



We can calculate Δp in this instance to be
$\Delta p = hs/2\lambda D = [(6.63 \times 10^{-34}\ \text{kg-m}^2/\text{s})(2.7 \times 10^{-2}\ \text{m})]/[2(650\times10^{-9}\ \text{m})(7.61\ \text{m}) = 1.81 \times 10^{-30}$ kg-m/s.
We can check this by seeing if it is approximately consistent with the Uncertainty relation
$\Delta p \Delta x = h/2\pi$.
Let's use it to calculate an approximate value of Planck's Constant:
$h = 2\pi\Delta p\Delta x = 2(3.14)(1.81 \times 10^{-30}\ \text{kg-m/s})(2 \times 10^{-4}\ \text{m}) = 2.27 \times 10^{-33}$ kg-m/s.
This is "in the ballpark" of $h = 6.63 \times 10^{-34}\ \text{kg-m}^2/\text{s}$, which is about all we expect.

Expected results using supplied data
The results that can be read from the supplied data can be summarized in this table:

Event	App (mm)	Width s (mm)	Width s (m)	Δx (m)	Δp (x 10^-30 kg-m/s)	1/(Δx) (m^-1)
1	0.3					
2	0.4					
3	0.5					
4	0.6					
5	0.7					
6	0.8					
7	0.9					
8	1					

We then plot:
- Δp as a function of Δx
- Δp as a function of $1/\Delta x$

and we find the slope.