LIGHT AS A RULER TO MEASURE OBJECTS TOO SMALL TO SEE (DIFFRACTION)

You will use a laser and diffraction to determine the spacings in patterns printed on a transparent film that are too close together to see by eye.

This experiment requires two people.

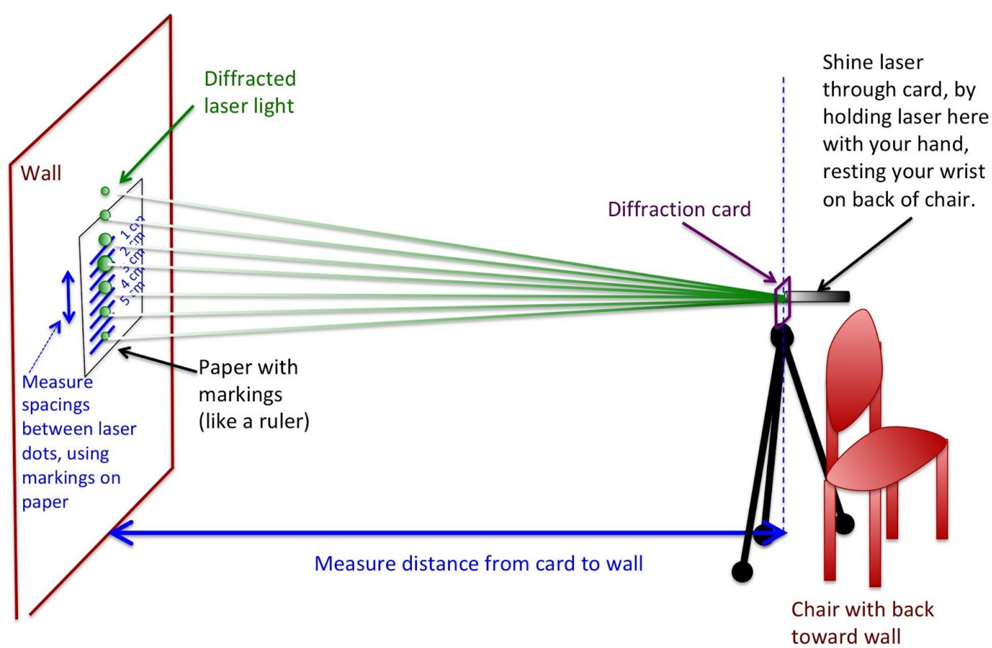
Materials:

- White Paper with Ruler Markings on it (for example, in 1 cm gradations)
- A measuring tape
- A pen or pencil
- Discovery Diffraction Card (from Institute for Chemical Education, https://icestore.chem.wisc.edu/)
- (Optional: 531 lines/mm diffraction grating from Rainbow Symphony)
- Tripod to which to secure the diffraction card
- Chair with a back
- One set of dark glasses or laser goggles to minimize the chances of looking directly into the laser light.
- At least one laser pointer (< 5 mW), laser pointers of different colors will enhance the experiment

Caution: Avoid direct eye exposure. Do not look or stare directly into the laser beam.

Instructions:

1. See figure below. This is the final setup for this experiment.
2. Tape the paper that has markings like a ruler to the wall. Position it at a height above the ground like that of the top of the back of a chair.



3. At first, both people should stand as far away from the wall as possible. For example, at least 3 meters (about 10 ft. or more). The farther, the better. Take the tripod and the chair with you.

4. Put the chair down with its back facing the wall. Place the tripod down between the chair's back and the wall. Attach the diffraction card to the tripod. Make sure that the card is oriented so that when you are on the chair and facing the wall you can read the words from your side. The "Institute for Chemical Education" should be at the top and the letters "ICE" should be on the right side. (See photo.)

5. Adjust the height of the tripod so that the bottom of the card is just at the top of the chair's back.

6. Mark the place on the floor directly under the card, so that you can return to it during the experiment, in case the tripod gets moved. It is important that this location of the diffraction card, relative to the wall, does not change. Measure the distance. Convert this measurement to mm. (Note that 1 m = 100 cm = 1000 mm)

Measured distance from the wall to the card:__________________________(mm)

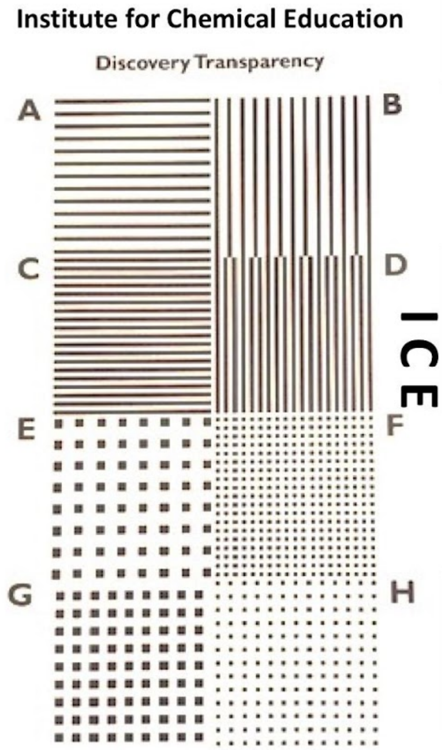
7. Look at the side of your laser pointer and record the wavelength of light that is written on it:

Wavelength of light of laser pointer: ____________(nm)

Convert this wavelength to mm (10^6 nm = 1 mm): ___________________(mm)

8. Rest your wrist on the back of the chair to steady your hand and point the laser through the card and to the wall at the ruler paper. (See photo.) Put the laser right up against the plastic film of the card to avoid reflecting the laser back to your eyes. Turn the laser pointer on by holding down the button. Move the laser pointer from one panel to another (A, B, C, etc.) of the card. (See photo.) **For each panel, draw the different laser dot patterns that you see on the wall into the table on the next page. How do dot positions and spacings of the laser light on the wall change with the line pattern and spacings on the card**?

Draw pattern for A, C, E, and G



Draw pattern for B, D, F, and H

9. **Person 1:** Put on dark sunglasses or laser goggles to minimize the chance of direct eye exposure to the laser. Stand next to the ruler paper on the wall with a pencil or pen. Look at the paper. Do not look at the person with the laser.

10. **Person 2:** *Warn Person 1 whenever you turn on the laser so they can turn away from you.* Hold the laser with your wrist stabilized on the back of the chair. Point the laser through the panel on the card so that you see a vertical pattern of dots at the ***widest*** spacing. (Be sure to place the end of the laser pen right against the film to avoid reflecting laser light back to you.)

Do NOT point the laser at the first person. *Caution: Avoid direct eye exposure to the laser. Do not look or stare directly into the laser beam.*

Which lettered panel is this on the card? ___________________

11. **Person 1:** With eyes focused on the wall (do NOT look back into the laser), with the pencil or pen, mark the locations of the central, most intense dot, and either the first (n-=1), second (n=2), or third (n=3) dot away from the central dot. (You can use the dots on either side of the central dot.)

n^{th} location of the dot from the central dot (n = 1, 2, 3, 4, etc.):________________
What is the measured spacing (on the wall) between this dot from the central dot (in cm)?
_________________________(cm)
Convert this dot spacing measurement to mm: _________________________(mm)

12. **Person 2:** Now pass the laser through the panel that gives you the ***narrowest*** spacing between the vertical pattern of dots.

Which panel is this? __________________

13. **Person 1:** With eyes focused on the wall, measure the spacing between the central intense dot and the dot at the same n^{th} location as before.

What is the measured spacing (in cm)? _________________________

Did the distances between spots increase or decrease with the decreased line spacing on the card?

14. **Person 2:** Now repeat #10 and #11 above, but with a second, different colored laser pointer, if you have one.

Wavelength of light of laser pointer: ____________(nm)

Convert this wavelength to mm (10^6 nm = 1 mm): ___________________(mm)

n^{th} location of the dot from the central dot (n = 1, 2, 3, 4, etc.):________________

What is the measured spacing (on the wall) between this dot from the central dot (in cm)?
_________________________(cm)

Convert this dot spacing measurement to mm: _________________________(mm)

Compare with the measured distances with the other laser. What happens to the dot spacings when the wavelength of the laser is shorter?

15. Now repeat #10 and #11 above, but with a third, different colored laser pointer, if you have one.

Wavelength of light of laser pointer: ____________(nm)

Convert this wavelength to mm (10^6 nm = 1 mm): ___________________(mm)

n^{th} location of the dot from the central dot (n = 1, 2, 3, 4, etc.):________________

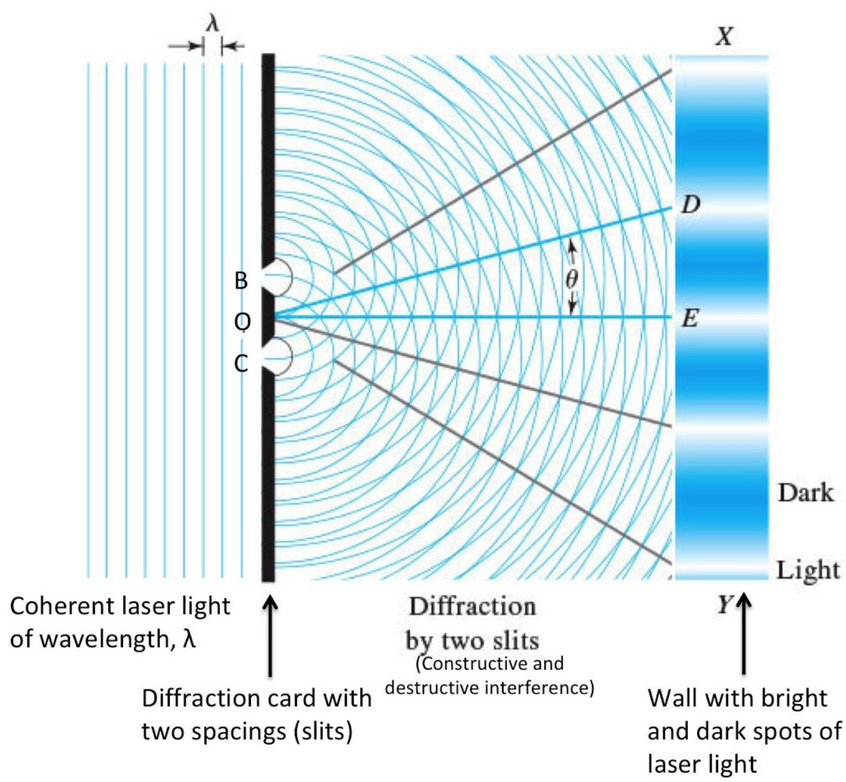
What is the measured spacing (on the wall) between this dot from the central dot (in cm)? _________________________(cm)

Convert this dot spacing measurement to mm: _________________________(mm)

Compare with the measured distances with the other laser. What happens to the dot spacings when the wavelength of the laser is shorter?

16. Now for some discussion and quantification (calculations).

When your laser light passes through closely spaced lines on the card, it bends and will constructively and destructively interfere with light passing through neighboring spacings, as shown through the plane B O C in the figure (representing the diffraction card). In the figure here, each blue curve represents the crest of one wave cycle. When a crest intersects with another, they constructively interfere (light). When a crest intersects with a trough of a wave, then destructive interference occurs (no light). When constructively interfering waves reach the wall, that is where you see bright spots; where waves destructively interfere, you see absence of spots.



An equation that relates the distances that you measured between spots on the wall, the wavelength, and the distance between the card and wall is given below:

$$n\lambda = \frac{(\text{line spacing on card panel})(\text{location of nth band from central band on wall})}{(\text{distance between wall and card})}$$

You can calculate the spacing between the lines in those two panels on your card, using the wavelength, λ, of the laser light and the other measurements that you made. Just rearrange the equation to solve for "line spacing on card panel" and then insert the values of the different measurements and calculate. Make sure that the units of length are all the same (such as all in units of mm).

(a) For the data obtained with the first laser:

What is the distance between the lines in the panel that gave the *widest* vertical dot spacing?

What is the distance between the lines in the panel that gave the *narrowest* vertical dot spacing?

(b) Do the same calculations for the measurements made with the other lasers having other wavelengths.

What is the distance between the lines in the panel that gave the *widest* vertical dot spacing?

What is the distance between the lines in the panel that gave the *narrowest* vertical dot spacing?

Compare the line spacings on the panel of the diffraction card as determined by using the lasers of different wavelengths. Do you get the same result?

(c) If you knew the spacings between lines in the card but not the wavelength of the laser light, how could you determine the wavelength of light?

Optional

17. Replace the diffraction grating with the other grating card that has even finer lines.

18. Calculate the spacing between the grating lines in this new card, based on the manufacturer's value of 531 lines/mm.

19. Shine the different colored lasers through the grating and measure the distances between the spots projected onto the wall. Are you surprised?

    What is the dependence of the distance between spots on the wavelength? Is it directly proportional (linear, so that wavelength 1/wavelength 2 = spot distance 1 / spot distance 2) or inversely proportional, etc.? Is your finding the same as when you used the diffraction card with the lines separated by larger gaps?

20. Measure the distance between the closest-spaced spots on the wall, assume n=1, and using the equation above, calculate the spacing between the grating lines for this card. Compare this value with the known grating lines. How close is this measurement?