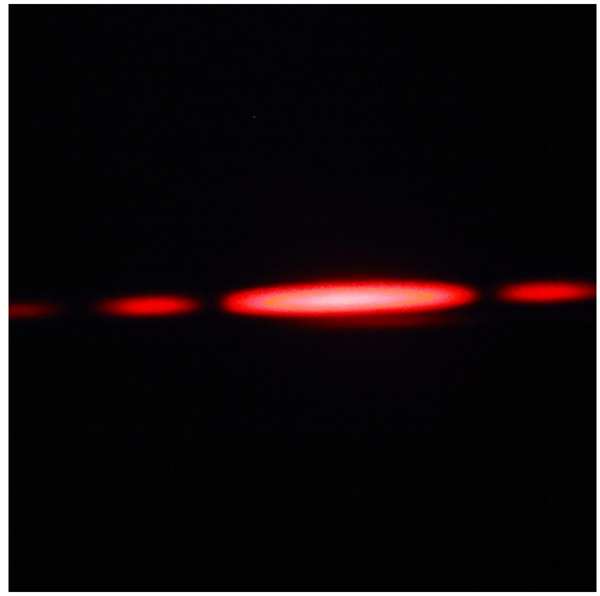
Hair Diffraction

Workshop

Participants use a hair to show how light can interfere to produce a diffraction pattern.



Stony Brook University

Number of Participants: Unlimited

Age Range: Elementary (5-10) and up

Duration: 20-30 minutes

Difficulty: Level 1

Materials Required:

- 2 Laser pointers of the same known wavelength
- A hair
- Tape
- Ruler

Setup:

1. Tape a strand of hair over the source of a standard low power laser pointer. Make sure that the tape does not influence the beam path.
2. If desired, tape the on button down so that the point can be mounted or placed easily while still lasing.
3. Point the laser pointer at a wall such that it displays a diffraction pattern. Note that the larger the distance from the wall, the better the length measurements are but the weaker the observed pattern will be. A dark or dim room is recommended.
4. Mark the darkest spots of the pattern (minima) on a sheet of paper or chalk board. Measure the distance between the center bright spot to each minima to find the hair diameter.

Presenter Brief:

Briefly introduce the idea of a laser. Highlight that small obstructions can cause the wavelike behavior of light be evident. Explain what diffraction is. Highlight the differences between single- and double-slit diffraction.

Vocabulary:

- Interference – Interaction between waves that can either increase their amplitude (constructive), or decrease it (destructive).
- Diffraction – Light's interaction with narrow slits or edges which causes it to spread out.
- Fringe – The interference pattern that arises from diffraction.

Physics & Explanation:

Elementary (ages 5-10):

When encountering a small obstacle, waves of light spread around the obstacle and interfere with each other. This effect, called diffraction, is an example of the wave-like nature of light.

Collect a thick strand of hair (darker colors are usually thicker) from a volunteer. Place the hair over the front of the laser and display the diffraction pattern on the wall.

Collect a thin strand of hair (lighter colors are usually thinner) from a volunteer. Display the diffraction pattern using another laser of the same wavelength.

Light is made of individual particles, called photons. Photons display the properties of waves, including diffraction. The diffraction patterns generated by different people's hair will vary because the diameter of each hair is different. The differences can be used to identify hair thickness to a high accuracy.

Middle (ages 11-13) and general public:

After completing the previous section:

The pattern of alternating bright and dark spots occurs because of constructive and destructive interference. When waves interact constructively, light intensity adds, as seen in Figures 1 and 2. Destructive interference occurs when waves are out of sync by an odd multiple of one-half wavelength (meaning peaks and troughs perfectly overlap) and effectively cancel. Both constructive and destructive interfernece are shown in Figures 1 and 2.

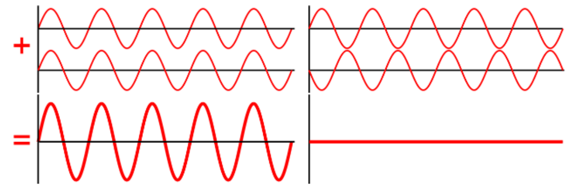


Figure 1: Constructive (Left) and Destructive (Right) linear superposition of waves. *Modified from: original version: Haade; vectorization: Wjh31, Quibik (Vecorized from File:Interference of two waves.png) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0) or GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons*

Display or replicate Figures 1 and 2 to illustrate constructive and destructive interference. Show the diffraction pattern again to highlight the destructive interference occurring at the minima.

Destructive interference of the light waves is seen in the dark spots of the diffraction pattern.

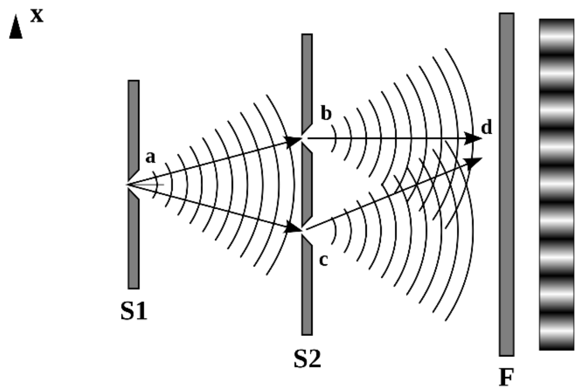


Figure 2: Diffraction pattern of two identical sources. *By en:User:Lacatosias, User:Stannered (Image:Ebohr1.png) [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/)], via Wikimedia Commons*

When the laser passes around a hair, laser light diffracts (or bends around a hair), effectively making two sources that are close to each other. Thus, if you look at the pattern on the wall, some light must travel a greater distance before reaching a point on the wall. If the difference in distance traveled to a given point of two waves is equal to exactly an odd multiple of one-half of a photon wavelength, the maximum of one wave cancels with the minimum of another wave, and the waves cancel. This is called destructive interference.

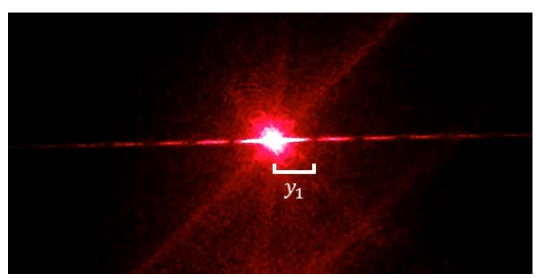
Point out the relationship between hair diameter and angle. As the hair gets thinner, the distance between minima gets larger.

After passing the hair, the light rays travel different distances before reaching the wall. The waves either add together or cancel each other out to make the diffraction pattern on the wall.

High School (14 +):

The approximate distance from the central maximum to a given minimum is given by y_m, where m is the number of minimum as counted from the center is given by:

$$y_m = \frac{\lambda D}{d} m$$



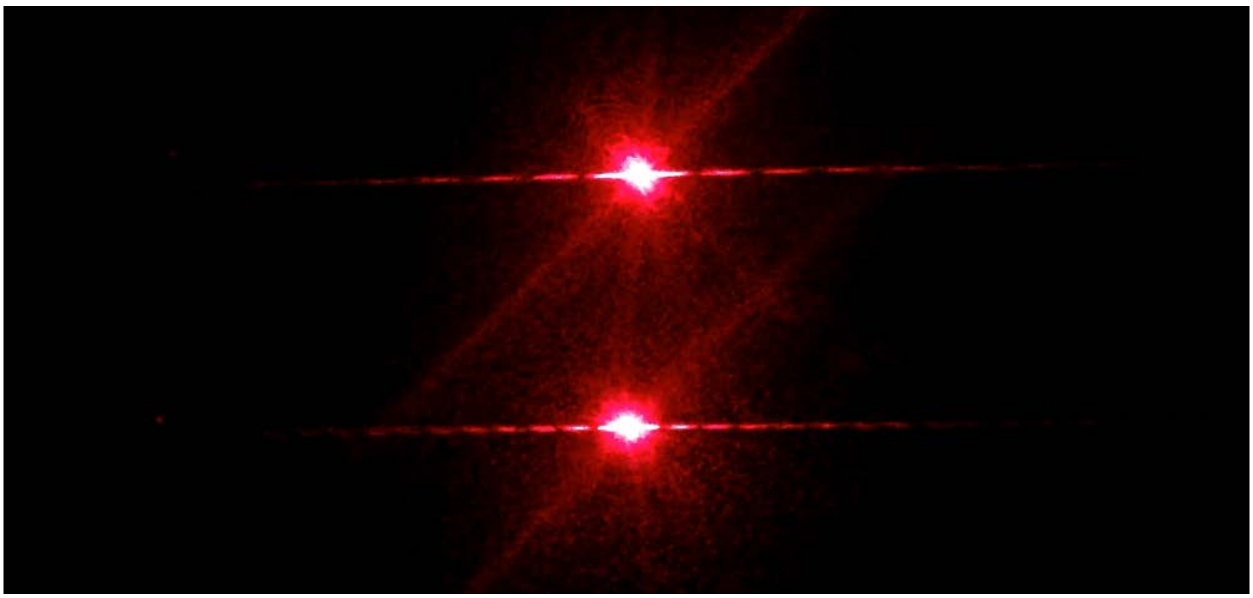
where the wavelength of light is λ, the distance from the laser to the wall is D, and the diameter of the hair is *d*.

Since measuring the width of the hair is difficult, we can instead measure the diffraction pattern minima y_m and the distance from the wall to the laser D to solve the above equation for the hair diameter d. The wavelength of your laser λ is printed on the label or can be researched[1]. For example, many inexpensive red laser pointers operate at ~650 nm. Solve maximum distance y_m for the hair diameter d with $m = 1$

$$d = \frac{\lambda D}{y_1}$$

Place a sheet of paper on the wall and instruct the participant to mark the central maximum with a line. Next, mark the 3-4 minima (dark spots) closest to the maximum. Measure the separation of dark spots and the distance between the laser and the wall. Using the equation above, find the width of the hair. Human hairs usual range between 20 μm and 200 μm in diameter.

Calculate the width of an obstacle (hair) if the wavelength of the laser light is known. Explore how this varies from person to person.



Additional Resources:

- Experiments with Diffraction http://www.optics.rochester.edu/workgroups/berger/EDay/EDay2008_Diffraction.pdf
- 2010 Sock https://www.spsnational.org/sites/default/files/files/programs/2009/sock/2010-sps-sock-manual-final.pdf
- Hecht. *Optics*, 1998. 499-501.
- Pedrotti, Frank L. and Pedrotti, Leno S. *Introduction to Optics*, 1997. 31-36.
- [1]https://en.wikipedia.org/wiki/List_of_laser_types

Useful Equations:

Distance from central bright spot to dark spot	$y_m = \frac{\lambda D}{d} m$

$d - width\ of\ slit\ (or\ diameter\ of\ hair)$

$\theta - \ angle\ measured\ from\ central\ maxima\ to\ the\ minima$

$\lambda - wavelength\ of\ light$

$D - distance\ from\ laser\ to\ wall$

$m - fringe\ number$