

Measuring the Diameter of a Human Hair by Laser Diffraction

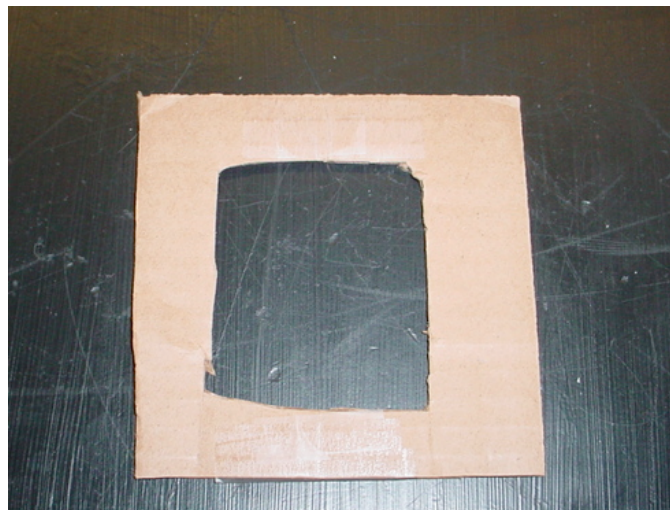
Introduction

Often it is necessary to determine the diameter of a fine wire, thin thread or other object that cannot be measured by conventional means. These items can be measured by using methods of diffraction and interference known as Young's Double Slit Experiment.

While Young's experiment deals with the pattern of light impinging on two narrow slits separated by a small distance, the method can be applied to an object with a small diameter as well. Where the diameter is within an order of magnitude of the wavelength of laser light used.

Procedure

1) Take a 15 cm by 15 cm piece and make a 10cm by 10cm hole in the center of the cardboard piece. This is your mounting bracket.

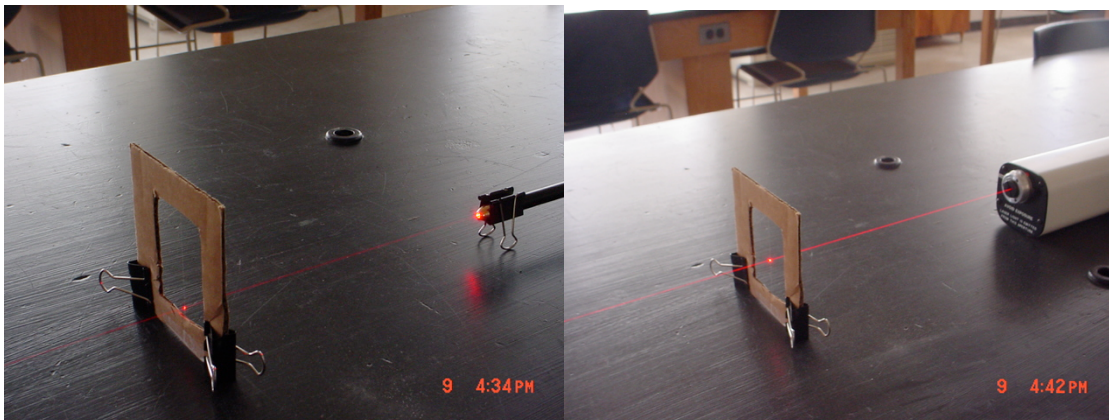


2) Select one strand of hair approximately 15-25cm long. This hair needs to be mounted on the mounting bracket from step 1.

3) Mount the hair on the bracket using tape. Place the hair so that it bisects the mounting bracket. Make sure the hair is taut and straight.

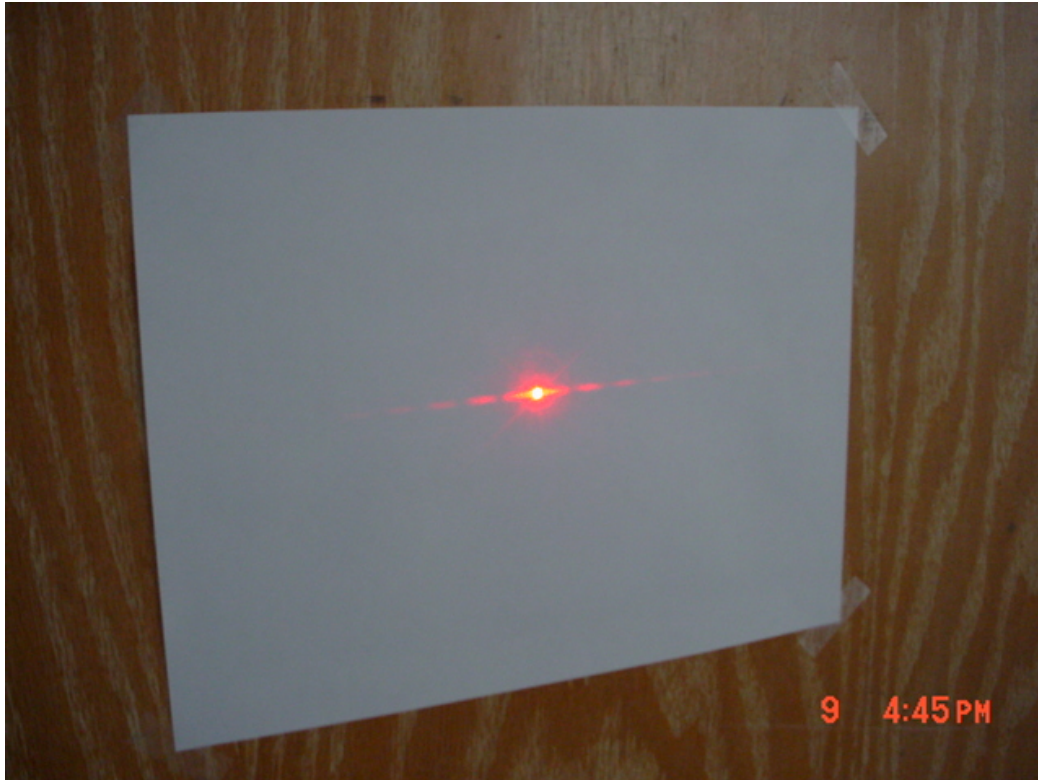


4) Set the laser pointer (or laser) on the lab table. Positioning the laser so the beam strikes the hair in the mounting bracket. (You may use binder clips or books to position the laser source and the mounting bracket on the table.)



5) Make sure the laser setup and mounting bracket face a wall or screen.

6) Record the following key parameters on the data sheet provided. Record the wavelength of the laser as λ . In some case to maybe necessary to average the wavelength values given on the laser's label. Typical values for a red HeNe Laser are 632 nanometers – 634 nanometers. Red laser pointers have a typical range between 630 nm – 680 nm. Record the distance (D) between the mounting bracket and screen or wall. (If you are using a wall for a screen it might be prudent to tape a piece of white paper on the wall to use as a background.)



7) Examine the pattern striking the screen. It should appear similar to the image below. (You may need to darken the work area or room to see the faint higher order bands.)



8) Carefully measure the bright bands by measuring from the center of the bright central band to the starting edge of first bright band on the left. Record this value as y_{li} , under the y_{mi} column. (You may find a bright spot in the center of the central band. This point can be used as reference.) Measure from the center of the central band again to the end of the first bright band on the left. Record this as y_{lf} , under the y_{mf} column. The average of these two measurements is the distance between the central bright band and the 1st order maximum ($m=1$) on the left side. Record this on the data table as y_{lavg} under the y_{mavg} column on the data sheet. Repeat the steps for the 2nd, 3rd, 4th, and 5th order bands. If you can see the bands beyond $m = 5$, measure those as well. Make sure you measure from the middle of the central band to the beginning and the end of each of the m^{th} order bands. (You may have to darken the room to see all the bands.)

9. After measuring all the bands on the left. Proceed to measure the m^{th} order bands on the right side of the central band using the same techniques outlined in step 8. This should yield a total set of at least ten measurements.

10 For each y_{mavg} calculate the diameter of the human hair (d) using:

$$d = (\lambda m D) / y_{mavg}$$

11) After determining the ten values of d calculate the average diameter of a human hair and the standard error (α_d) in the measurement of d . where the standard error is the standard deviation of d divided by the square root of the number of measurements taken.

$$\alpha_d = S_d / N^{1/2}$$

Example Calculations

Example for the 1st order (m=1) band for a HeNe laser $\lambda = 633 \text{ nm}$, and screen distance of $D = 1.5 \text{ m}$.

$$d_1 = (633 \times 10^{-9} \text{ m})(1) (1.5) / (0.02 \text{ m}) = 4.75 \times 10^{-5} \text{ m or } 47 \mu\text{m}$$

Example for the 4th order (m=4) band for a HeNe laser $\lambda = 633 \text{ nm}$, and screen distance of $D = 1.5 \text{ m}$.

$$d_4 = (633 \times 10^{-9} \text{ m})(4) (1.5) / (0.0575 \text{ m}) = 6.61 \times 10^{-5} \text{ m or } 66 \mu\text{m}$$

Going Further

Try the same experiment on a needle or pin.

Questions

1) Research the acceptable values of the thickness of a human hair. You may use the Internet, life science and physical science textbooks or measure the hair yourself by using a micrometer. What is the range of values for human hair?

2) Average the range of values of human hair. What is the percent difference between your average value and the average accepted value?

3) What other items could you measure using this technique?

Diameter of a Human Hair Data Sheet					
Laser wavelength $\lambda =$					
					Calculated
m	m	Y_{mi}	Y_{mf}	$Y_{m\ avg}$	diameter
+7	7				
+6	6				
+5	5				
+4	4				
+3	3				
+2	2				
+1	1				
0	N/A			N/A	N/A
-1	1				
-2	2				
-3	3				
-4	4				
-5	5				
-6	6				
-7	7				
			Average Diameter		
			Error		

Diameter of a Human Hair

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Bibliographic Entry	Result (w/surrounding text)	Standardized Result
Piezo Technology . Epson (UK) Ltd.	"45 microns, 2 times smaller than the diameter of a human hair and close to the limit of resolution for the human eye"	90 μm
Denny R's Homepage . Denny & Gayle Rossbach. Palmdale, CA.	"Diameter of a human hair inches: 0.001; centimeters: 0.00254"	25.4 μm
Why Choose A Water Treatment System? Aqua-Fresh Drinking Water Systems, Inc.	"Particulate contaminants including asbestos, rust, sediment, dirt, and scale as small as 0.2 microns (1/300th diameter of a human hair)."	60 μm
Hair - Important Facts About Hair . CAQTI Cosmetics, Inc.	"Flaxen hair is the finest, from 1/1500 to 1/500 of an inch in diameter ... and black hair is the coarsest, from 1/450 to 1/140 of an inch."	17 - 50 μm (flaxen) 56 - 181 μm (black)

Hair can be found all over human body, except for the palms of hands and at the soles of feet. The purpose of hair is protective: the hairs on the body keeps a person warm, nose hairs prevent dust and dirt from entering the respiratory system, and eyebrows prevent sweat from entering the eyes.

The diameter of a human hair does not have a standard value since different people have different hair structures. Your genetic makeup can cause the width of your hair to differ from that of other people. Hair color is also a big factor. Black hair is thicker than is red hair. The weather can also affect the diameter of a hair strand. As the weather gets warmer, the diameter of body hair increases. Age is another factor. Babies and young children have finer hair than adults. As a person grows up, their hair becomes thicker and stronger. Another factor is that, the closer to the root of the hair, the thicker a strand of hair would be.

In my research, I have found the diameter of human hair to range from 17 to 181 μm (millionths of a meter).

Brian Ley -- 1999
