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 measure by convectional means. These items can be measured by using methods of diffraction and interference known as Young's Double Slit Experiment.

While Young's experiment deal with the pattern of light impinging on two narrows 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.
How can we measure the diameter of a human hair? One can think of several methods how to do it (micrometer screw gauge can be used for example). We are going to measure the diameter of a human hair by diffraction of a laser beam. The thickness of the human hair is just a bit more than a magnitude of the laser light used.

Objectives

Completion of the activities should enable you:

- measure the diameter of a hair and wire using a He-Ne laser, steel rule, and meter stick.

Materials:

He-Ne laser, hair, steel ruler (instead of diffraction grating), white screen, meter stick, computer, Microsoft EXCEL (or any other software with graphing capabilities).

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.

Procedure

1. Position one of your hairs in front of the laser (you can fix it on the laser or use a stand). When fastened make sure that the hair is straight.

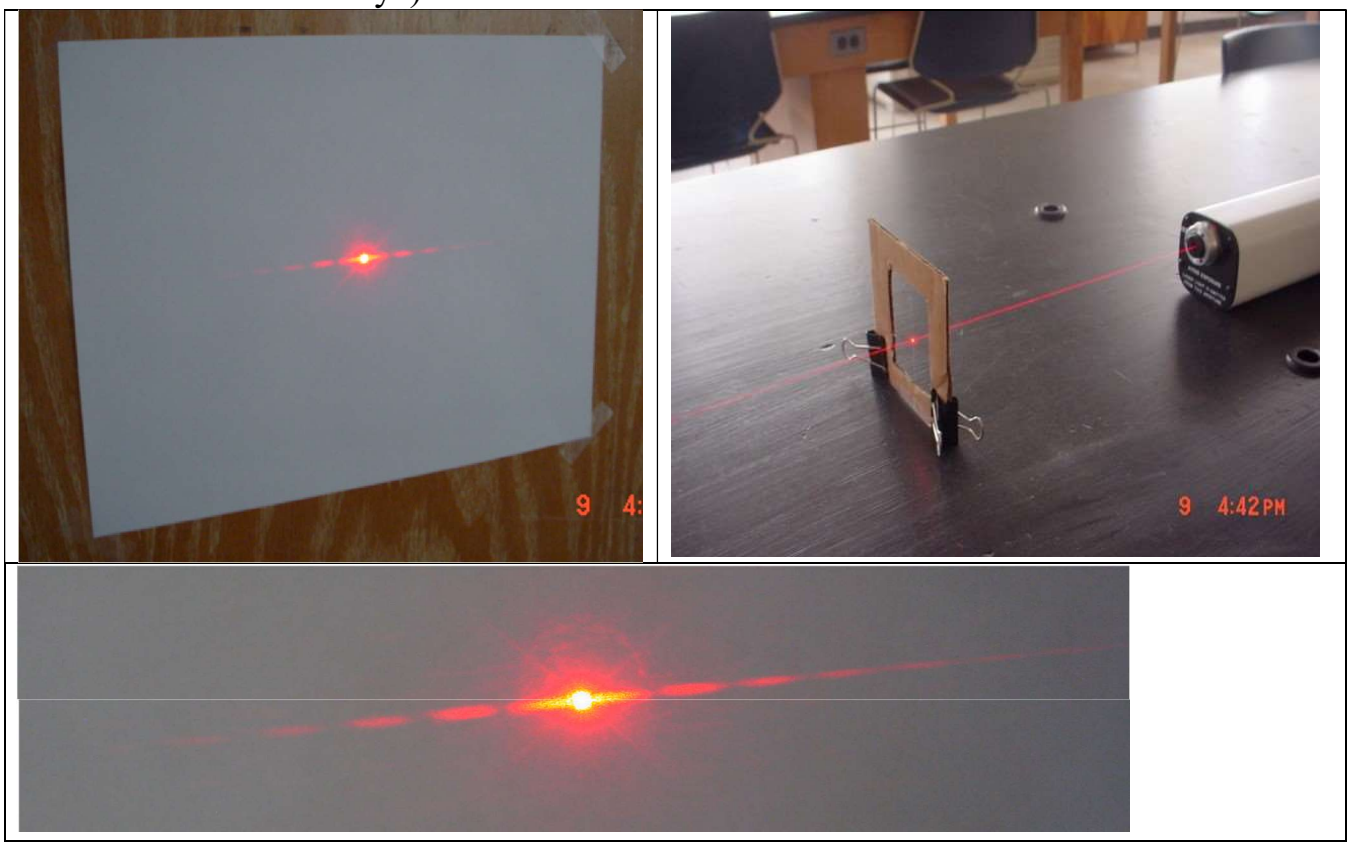
(You may need to darken the work area or room to see the faint higher order bands.)

2. By trial and error put the screen at a place where the diffracted spectrum is clear enough to be studied.
3. After setting up the laser at the appropriate location make the necessary measurements, needed to determine the wavelength, of θn, D and n (use several minima and average the values to get the final wavelength):

- θn will not be calculated directly. Instead you will measure D (distance from the hair to screen – this measurement is taken only once because the distance from the hair to screen does not change) and X (distance from the central maxima to the nth minima), with a meter stick and then use the trigonometric identity:

$$\theta_n = ta^{-1}(X_n/D)$$

- The number of minima (n) was counted directly from the screen (try to get a big number of minima. Why?).



Record your data in the following table:

					Calculated
N	|n|	Xni	Xnf	Xn avg	Diameter
+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				

For each $X_{n\ avg}$ calculate the diameter of the human hair (d) using:
$d = (\lambda\ n\ D) / X_{n\ avg}$

Example Calculations

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

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

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

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

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

The Physics Factbook™
Edited by Glenn Elert -- Written by his students
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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 [1]7 to 181 µm (millionths of a meter).