Measuring the Large and the Small

Background:

We are familiar with a number of methods for measuring visible objects. Tools for measuring vary according to the size of what is to be measured. For example, it would be inconvenient and time consuming to use a centimeter ruler to measure the length of a football field or even the length of a basketball court. Multiple errors would be introduced each time the ruler had to be moved length to length to measure the entire distance. A long tape measure would be more appropriate. Meter sticks can be used to measure objects like doorways or table widths or heights, and centimeter rulers are appropriate for objects smaller than the length of the ruler but larger than about 1.0 mm. Neither would be very precise for something like the width of a sewing needle, the thickness of a razor blade or the width of a human hair. Objects, openings (slit widths) or diameters can be measured accurately to a precision of ± 1.0 mm using a meter stick or metric ruler, and to about ± 0.010μm using a micrometer. The precision of an instrument is considered to be 1/10 the smallest increment on the scale.

For smaller objects, an even smaller scale must be used. The wavelengths of visible light vary from about 420 – 750 nanometers. Using a modification of Young's Double Slit Experiment, we can use the known wavelength of light from a He-Ne laser to measure very small objects by causing the light to diffract through or around the object. When waves are diffracted through or around objects, individual waves interfere with one another either by adding (when peaks coincide) or subtracting (when a peak coincides with a trough). When the diffracted light shines on a screen or flat surface some distance away, a row of bright spots, representing areas where interfering peaks coincide will result. The width of the opening or object can be determined by measuring the distance between each of these bright spots and the distance from the object to the screen. We use the equation:

$$d = \frac{\lambda L}{\Delta y}$$

Where: d = the width of the object or opening being measured

λ = the wavelength of light

L = the distance between the object and the screen

Δy = the distance between bright spots (for double or multiple slit gradients) or

Δy = the distance between dark spots (for single slit or width of a hair or fiber)

Purpose:

The purpose of this experiment is to measure objects of similar form (cylinders) but different sizes using the most appropriate method among meter sticks, centimeter rulers, micrometers or light waves. We will also measure the spacing between grids of the diffraction gradient in a pair of "rainbow" glasses.

Materials:
Large post or pillar. If you don't have that, use the width of a door.
1 ¼ inch dowel rod, 1/8 inch dowel rod, hat pin, dressmaker's pin, alligator-clip clothes pin, human hair, thick piece of cardboard measuring about 2 inches on a side, single hole punch, adhesive tape, "rainbow" glasses and student grade He-Ne laser.

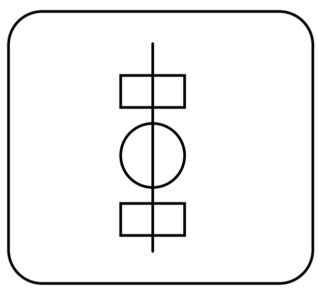
Procedure:

1. Measure the width of each object using the most appropriate tool. Choose among a meter stick, a centimeter ruler, a micrometer and the diffraction of light from the He-Ne laser.

2. Record the results in Table I on the data page and answer the questions that follow.

3. To measure width using the laser, set the laser up on a level surface about 1 to 2 meters away from a screen or flat, white wall. Place the object to be measured very close to the laser (within about 1 centimeter) and align it with the beam until a clear diffraction pattern appears on the wall.

4. To measure the width of a human hair, punch a hole in the center of the cardboard. Stretch the hair vertically across the hole and tape it at the top and the bottom to keep it straight.



5. Use the clothes pin to hold the hair directly in front of and in the middle of the laser beam. Adjust the card so that a distinct row of bright spots can be seen on the screen.

6. For the hair, measure the distance between any two dark spots. For the gradient glasses, measure the distance between any two bright spots.

7. If the spacing between bright or dark spots is greater than about 2 or three centimeters, use a centimeter ruler or a meter stick to measure the distance between the centers of 2 adjacent spots. If the spacing is closer than that, average the distance between spots in a row at least 15 centimeters long. For example, if a row of 12 bright spots measures 18.32 cm from the center of the 1^{st} and the center of the 12^{th} spot, divide 18.32 cm by 11 because there are 11 spaces between the 12 spots. The same applies for a row of dark spots.

Table I

Object	Tool	Precision	Width
post or doorway			
Thick dowel rod			
Thin dowel rod			
hat pin			
dress maker's pin			
human hair			
diffraction gradient			

Questions

1. What kind of errors can occur when a yardstick is used to measure

    a) the width of a football field?

    b) the width of a human hair?

2. What advantage to precision does the metric system have over the English system of linear measures?

3. How far apart would the bright spots of the laser (Δy) be if we were to use diffraction to measure the width of a carbon nanotube, 10nm wide?

Insight: ____

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