LAB # 9

Spectroscopy and the Nature of Light

OVERVIEW

Almost everything in the universe emits radiation. Astronomers study radiation to learn about the contents of the universe. In this lab you will find out how to use a spectroscope to identify different elements. In addition, you will explore the nature of light and color to elucidate the principles and phenomena associated with spectroscopic investigation.

Part 1: Spectroscopic Identification

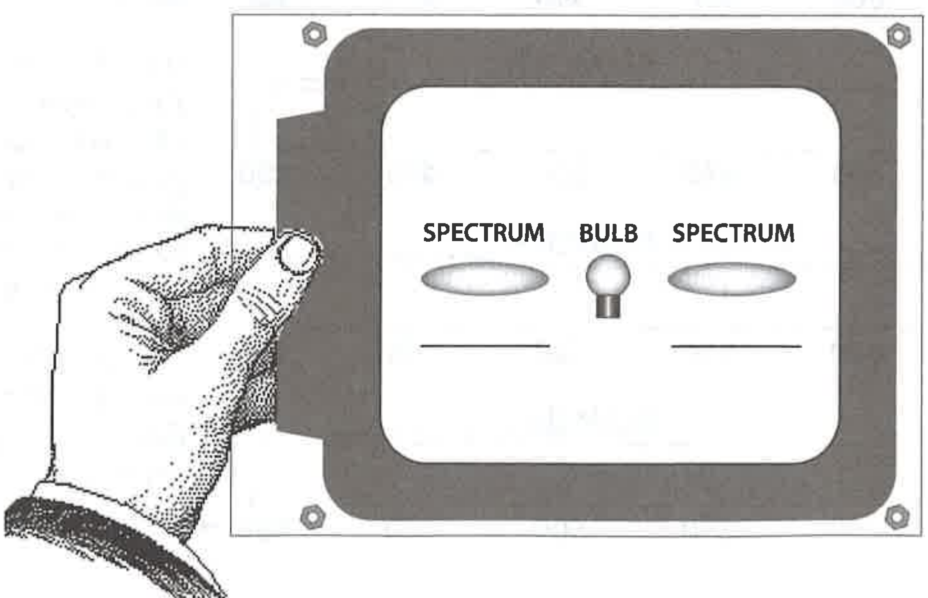
A device that breaks down light into its fundamental components or colors is called a **spectroscope**. A **diffraction grating** is a transparent material that has thousands of fine grooves ruled onto its surface. Each of these grooves is an aperture and **diffracts** or spreads out light that is incident upon it. In this part you will use a spectroscope that employs a diffraction grating to produce a spectrum.

Look through the diffraction grating at the light emitted by an incandescent bulb. You should see the bulb and a **spectrum** or bright strip of colors to the left and to the right of the bulb. Note that each spectrum shows all the colors of the rainbow - ***red, orange, yellow, green, blue and violet***. This type of spectrum is called a **continuous spectrum**.

In the view of the bulb and spectra below, label the locations of the colors on the lines below each spectrum using the letters **ROYGBV** to represent the six fundamental colors.

Which color appears closest to the bulb? _________

Which color appears farthest from the bulb? _________



Spectroscopy

Many minerals are observed to glow when they are heated in a flame. Spectroscopic analysis of this light has shown it to be composed of sets of specific colors or *wavelengths*. For example, if table salt (sodium chloride) is sprinkled into a candle flame, most of the light emitted is of two distinct shades of yellow, or at two specific wavelengths in the yellow part of the visible spectrum. The presence of light at those wavelengths indicates the presence of the element, sodium.

When an electric current passes through a gas, the gas will emit light of specific wavelengths. Each element has its own **spectroscopic signature** or pattern of wavelengths. *Why do elements emit only specific wavelengths when they are heated or electrified?* The answer is found in the structure of the atom: electrons absorb or emit only discrete amounts of energy.

In the lab room, there are four glass emission tubes each of which contains a small amount of a particular element. Each tube is mounted in a black metal box. Begin with the tube labeled ***Tube No. 1: HYDROGEN***. With the power switch turned on and the gas in the tube glowing, look through the spectroscope to see the spectrum of hydrogen. You should see three prominent colored images of the tube on each side of the actual tube, which appears to have a magenta glow. These are the spectral lines that distinguish the presence of hydrogen, the most abundant element in the universe. With reference to the spectrum you see to the left of the actual tube, draw the three lines in the appropriate places in the spectrum below. Use the colors noted in the continuous spectrum as an aid to help you draw the three lines.

CONTINUOUS SPECTRUM

RED ORANGE YELLOW GREEN BLUE VIOLET

Tube No. 1 **ELEMENT:** HYDROGEN

700 650 600 550 500 450 400

Tube No. 2 **ELEMENT:** ______

700 650 600 550 500 450 400

Tube No. 3 **ELEMENT:** ______

700 650 600 550 500 450 400

Tube No. 4 **ELEMENT:** ______

700 650 600 550 500 450 400

After drawing the spectral lines of hydrogen, draw the spectra emitted by the tubes labeled ***Nos. 1, 2 and 3***.

Use the chart titled **Emission Spectra of 10 Elements** projected on the lab room's rear screen to identify the elements in those tubes.

The numbers below each spectrum denote the wavelength (λ) in nanometers.

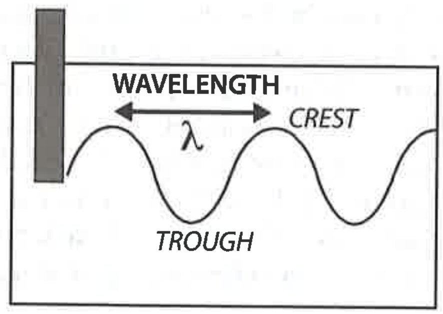
Part 2: The Wave Model Of Light

Numerous experiments with light have demonstrated that it has properties associated with waves. In the 1600s Christiaan Huygens showed that light exhibited pulse-like properties. The pulsations of the light from different parts of a candle form an expanding *wavefront*, similar to what occurs on the surface of water when pebbles are dropped into it. The wave nature of light was later employed by Thomas Young to measure a quantity that defines the different colors of light in the visible spectrum.

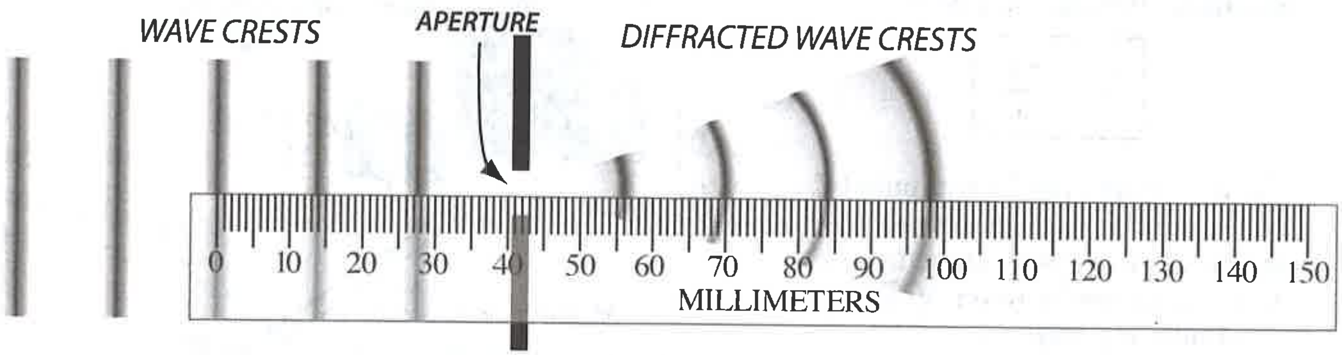
Before conducting a modern version of Young's brilliant experiment, become familiar with some terminology associated with propagating waves. These terms apply to water waves, sound waves and light waves.

Candlelight wavefronts

If you tap a board repeatedly on the surface of the water in an aquarium, you would make waves as shown in the diagram at right. The highest points of the waves are called **crests**. The lowest points are called **troughs**. The distance between two successive crests or troughs is called the **wavelength**, denoted by the Greek letter lambda, λ. Different types of waves are distinguished by their wavelengths.



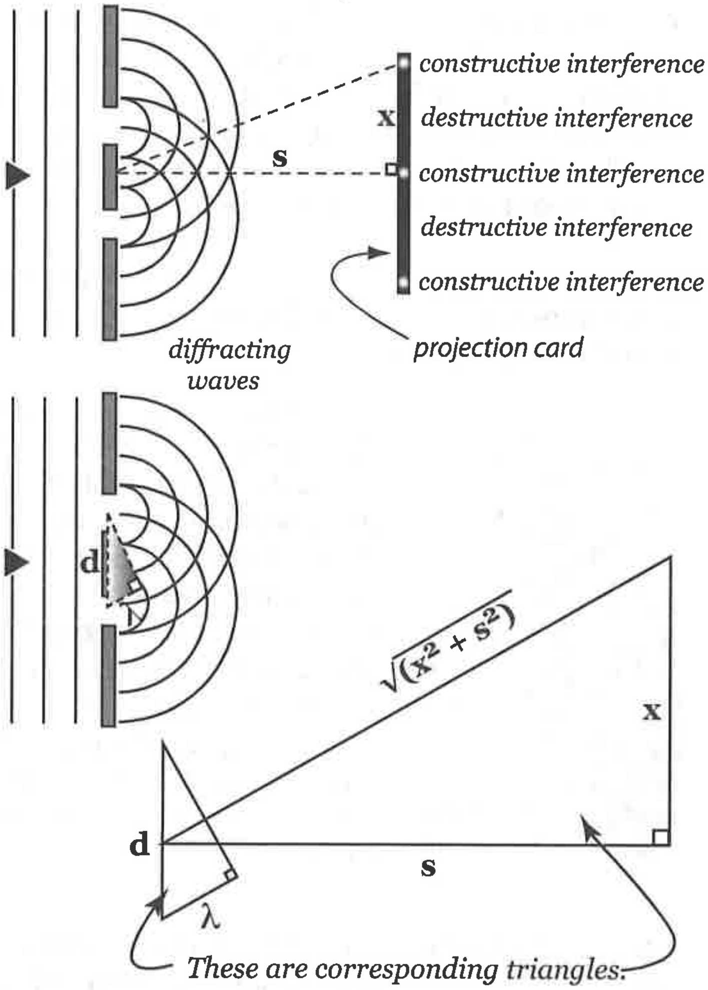
One way to measure the wavelength of water waves is to find the distance between two successive crests. Suppose snapshots were taken of the water surface as the waves pass through a small opening or **aperture**, where they spread out or **diffract**. By placing a ruler on the overlaid images below, the wavelength can be measure directly.



In the image above, measure the wavelength in millimeters: ______ mm. Note that it does not matter where the wavelength is measured - the value is the same if you measure it before or after the waves diffract. *Draw two additional diffracted waves on the right.*

The Wavelength of Visible Radiation

In the early 1800s Thomas Young measured the wavelength range of the visible spectrum using a pattern that he obtained from the diffraction of light through two apertures. The method is illustrated in the diagram at right.



When waves from two apertures diffract, they will interfere and produce a distinct pattern. Where the crests and troughs reinforce one another, constructive interference will occur. Bright spots of light will be seen on a card placed as shown. Where the crests and troughs meet so as cancel one another, destructive interference will occur, and no spot of light will be seen on the card. The sequence of bright and dark regions is called an **interference pattern**.

There are two corresponding triangles in the diagrams at right. The following proportion is true:

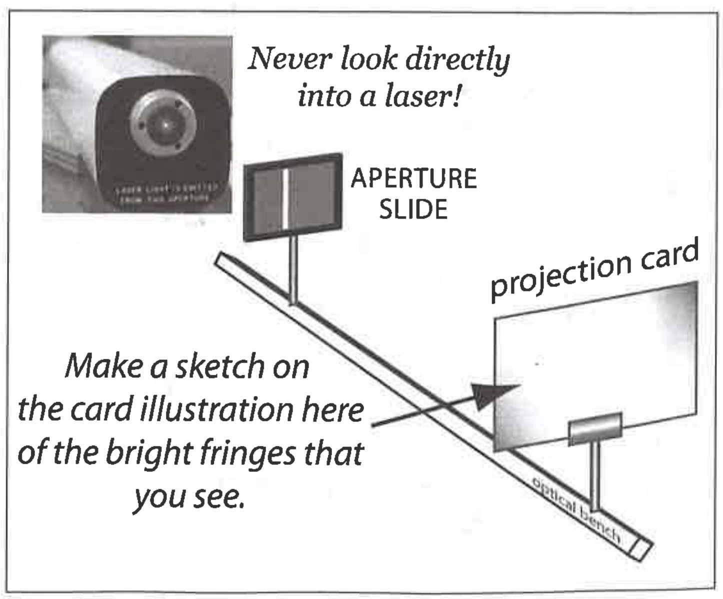
$$\boxed{\frac{\lambda}{d} = \frac{x}{\sqrt{(x^2 + s^2)}}}$$

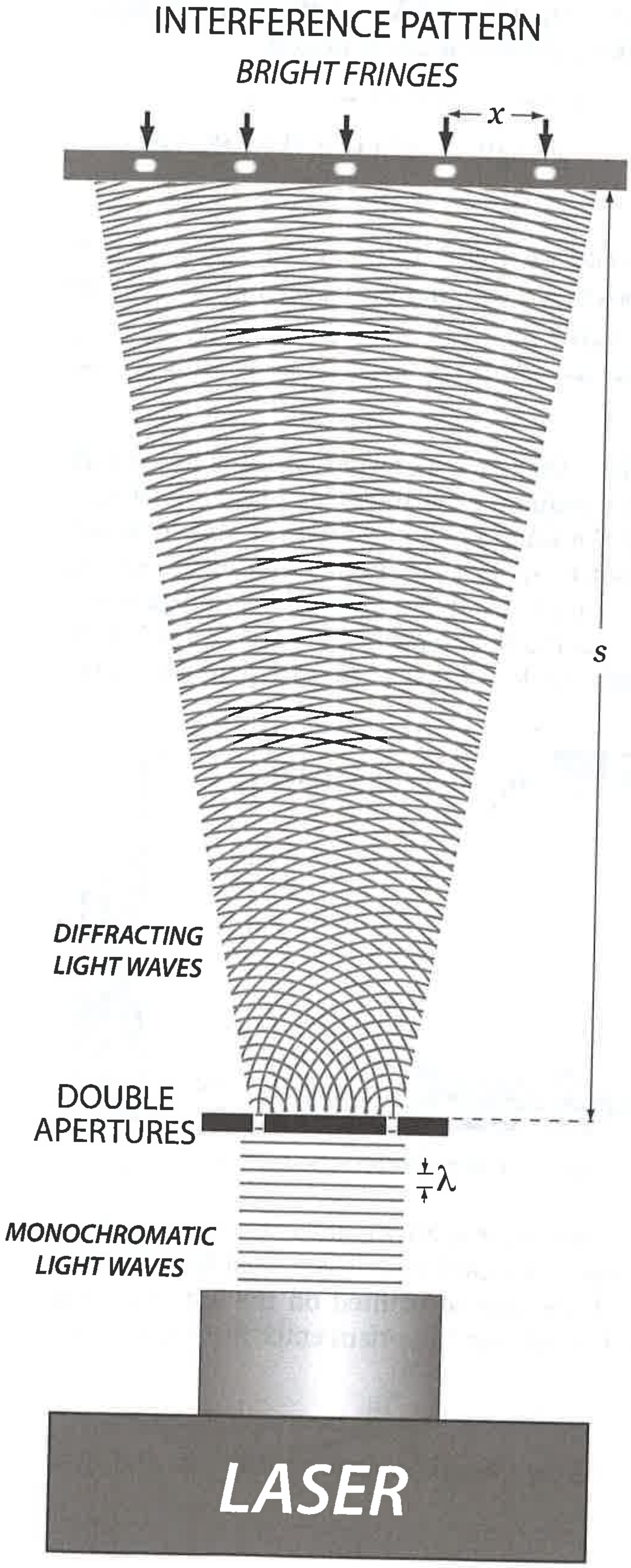
If **x** is small relative to **s**, the following approximation can be made:

$$\boxed{\lambda \sim \frac{d\,x}{s}}$$

The wavelength can be computed if three quantities are known:

d - the aperture separation
x - the distance between sites of similar interference
s - the distance from the point between the apertures to the line where **x** is measured

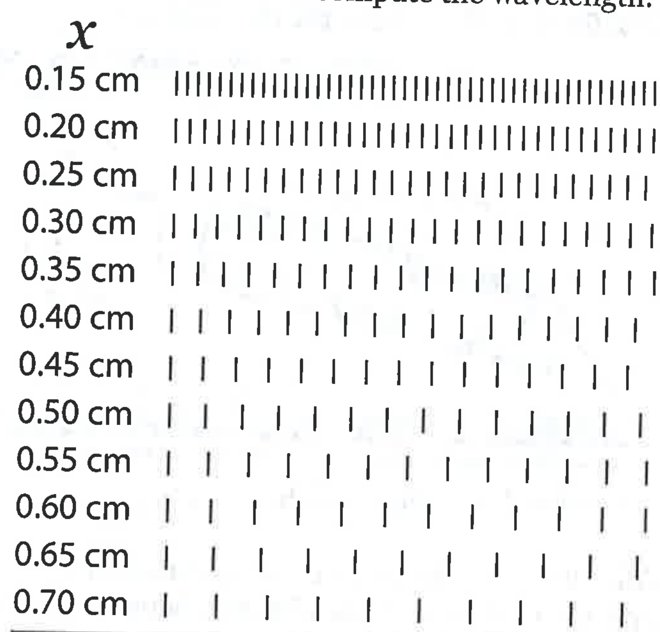




In this part you will use Young's method to measure the wavelength of laser light. The light emitted by a laser is **monochromatic**, which means that the light emitted is of one specific wavelength.

Refer to the diagram at the bottom of page four. Mount the laser, aperture slide and projection card on the optical bench. Place the laser at a distance of about 10 cm from the aperture slide. Place the projection card at a distance of 150 cm from the aperture slide. The apertures are 0.02 cm apart.

Turn on the laser and adjust the beam so that it falls on the pair of apertures that have the smallest separation. An interference pattern will appear on the card. Make a sketch of it in the diagram on page four. Hold the series of marks printed below directly in front of the projection card. Move the page to the row that best matches the actual interference pattern. The values of *x* are listed at the left. Record *x* in the table below and compute the wavelength.



d (cm)	0.02 cm
x (cm)	
s (cm)	150 cm
λ (cm) ~ **d x / s**	
λ_{actual} (cm)	0.000063 cm

• How many wavelengths of laser light would it take to span the thickness of a piece of paper? *(Hint: Suppose that it takes 100 pages to make a pile of paper one cm in height.)*

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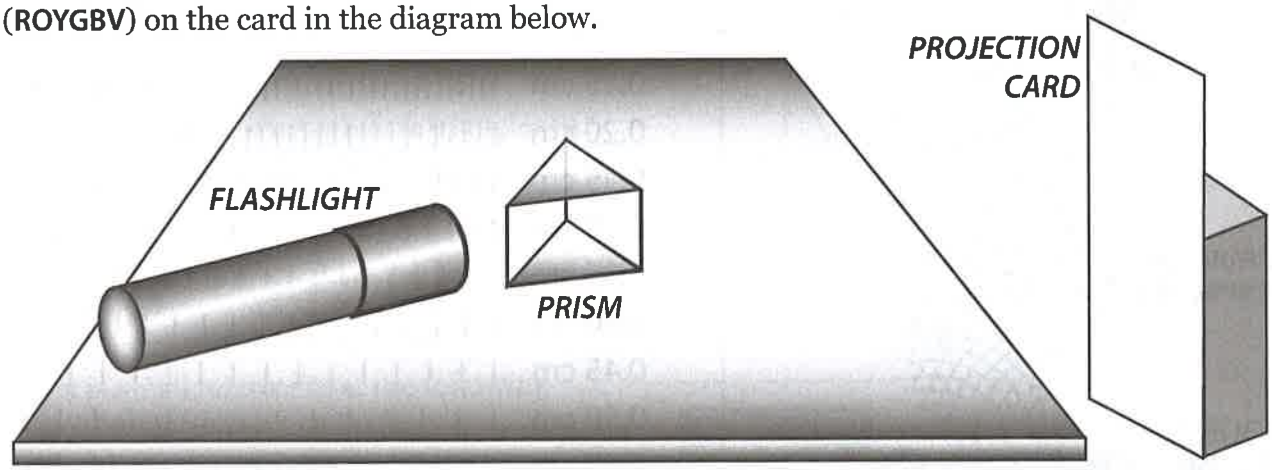
• Do you think you could see anything the size of the wavelength of light with the naked eye? ______ Why not? *(Hint: See Lab No. 4)* ______________________________

• If you replaced the red laser with a blue one, you would see bright fringes that are placed closer together than those produced with the red laser. Does that mean that the wavelength of the blue light is shorter or longer than the wavelength of red light? ______________________

Part 3: The Mixture of Colors

In the seventeenth century, Sir Isaac Newton examined very carefully what happens to sunlight when it is refracted by a prism. Recreate one of his notable experiments. Place a flashlight (our substitute for sunlight) a few centimeters from the square face of a prism as shown below. Adjust the prism so that the flashlight beam passes through that surface and exits another square surface. Using a white card standing about 25 cm from the prism, find the spectrum that emerges from the prism. *(You may have to focus the flashlight beam to obtain a bright, distinct spectrum.)* Draw the spectrum and label the locations of the six primary colors (**ROYGBV**) on the card in the diagram below.



• Which color is refracted the most? ________ Which color is refracted the least? ________

After you have formed a clear spectrum on the card, place a magnifying lens between the prism and the card so that the distance between the lens and the card equals the focal length of the lens. (The focal length is inscribed on the edge of the lens or printed on the envelope that protects the lens.) Adjust the lens so that the light rays exiting the prism enter the lens and are brought to a focus on the card.

• Describe the small spot of light that you see on the card at the focus. ________________

• What does this experiment tell you about sunlight, which appears white to the eye?

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