Ray Tracing, Color and Polarization

Overview: This lab has three distinct parts. The first part focuses on the way that light proceeds through transparent media in a straight line. You will use this characteristic of light to practice a powerful technique called Ray Tracing that allows you to locate objects and their images. In Part II you will become familiar with the nature of white light and observe light that is reflected and transmitted by Colored (but transparent) Filters. Part III introduces you to Polarization of light by transmission through a Polaroid filter as well as by reflection from the surface of a transparent medium.

Part I: Ray Tracing

Purpose: To observe the straight-line propagation of light. To use the technique of Ray Tracing to locate the position of an object.

Apparatus: Optics Bench, Light Source, Ray Table and Base, Component Holder, Slit Plate, Ray Table Component Holder, Viewing Screen.

Introduction: When light propagates through free space, the atmosphere, water (or other transparent media) or when it encounters objects whose dimensions are large (compared to the wavelength of the light), it is observed that the light proceeds in a straight line. We call these straight line paths “rays”.

Procedure: Set up the equipment as shown in Figure 1, and turn on the Light Source. Darken the room enough so the light rays on the Ray Table are easily visible.

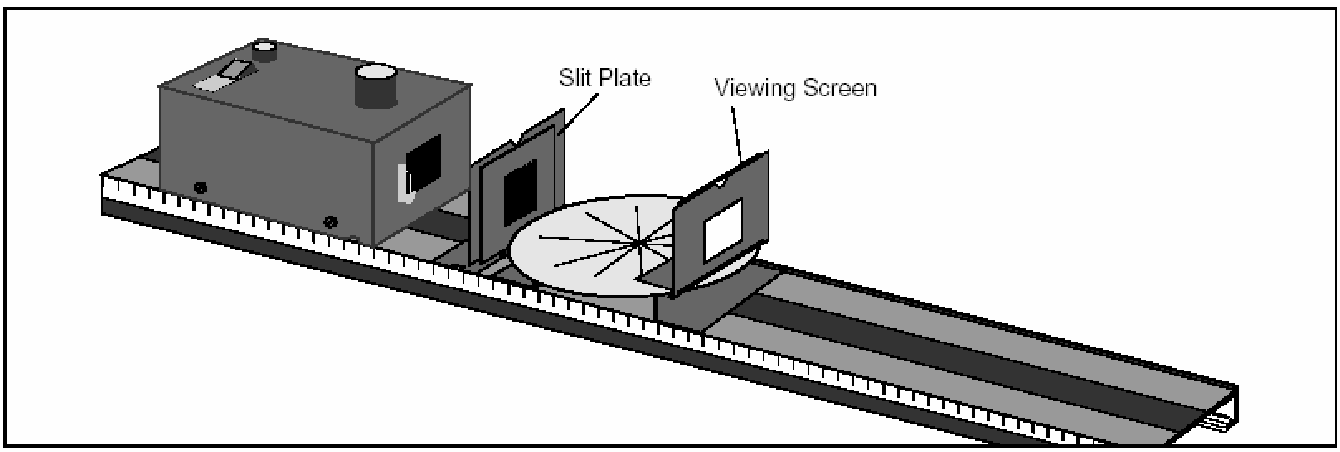

Figure 1 Experimental set-up for observing rays.

Straight Line Propagation of Light

Observe the light rays on the Ray Table and answer the following questions in your lab journal.

1. Are the rays straight?
2. Move the Viewing Screen to the far end of the Optics Bench. How does the width and distinctness of each ray vary as you move the Slit Plate away from the Light Source and toward the Viewing Screen?
3. Set the Viewing Screen and its holder aside for the next step. Lower your head until you can look along one of the "Rays" of light on the Ray Table. Where does the light originate? Is the

source filament oriented in a horizontal or vertical direction? What path did the ray take going from the source to your eye? Try this for several rays.

4. Return the Ray Table and Viewing Screen to their original positions as shown in Figure 1. Now, rotate the Slit Plate slowly on the component holder until the slits are horizontal. Observe the slit images on the Viewing Screen. How does the width and distinctness of the slit images depend on the angle of the Slit Plate?
5. For what angle of the Slit Plate are the images most distinct? For what angle are the images least distinct?

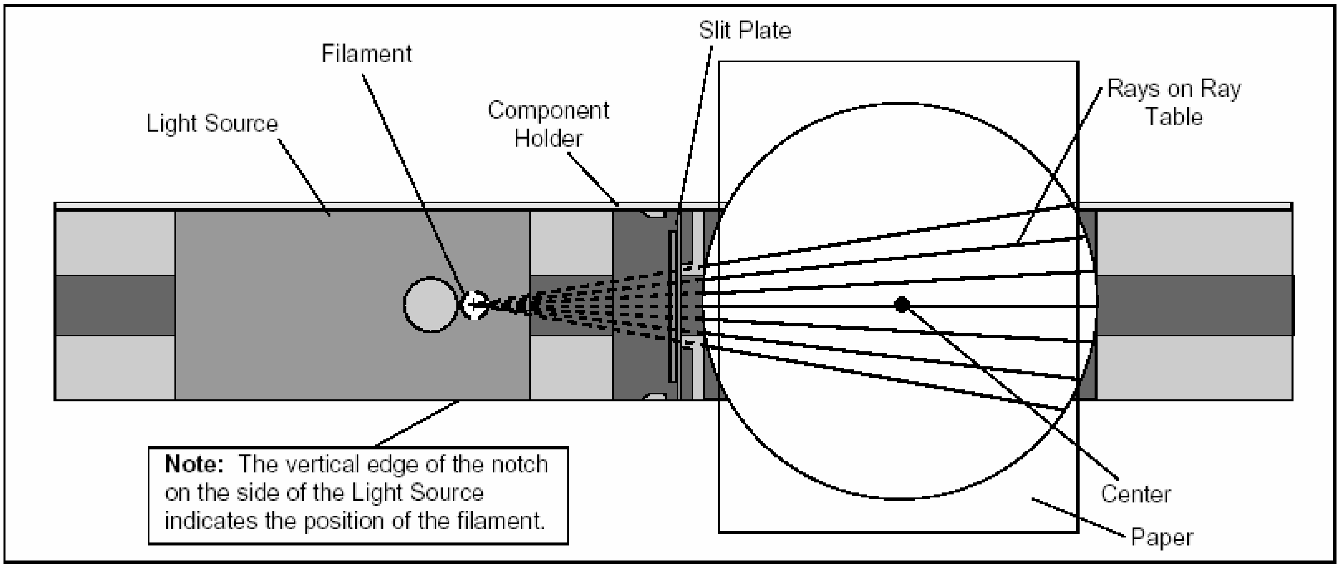

Figure 2 Experimental set-up for ray tracing.

Ray Tracing: Locating the Filament

You can use the fact that light propagates in a straight line to measure the distance between the Light Source filament and the center of the Ray Table. Figure 2 shows how. The rays on the Ray Table all originate from the filament of the Light Source. Since light travels in a straight line, you need only extend the rays backward to locate the filament. (See Step 3.)

6. Place a piece of blank white paper on top of the Ray Table, holding it there with a piece of tape. Make a reference mark on the paper at the position of the center of the Ray Table and be sure that the central ray lines up with the center of the Ray Table. The Light Source Filament can be adjusted by the knob on top – try it, and the Slit Plate can be adjusted too.
7. Using a pencil, make two marks along the same edge of each ray, directly onto the sheet of paper. You will use these marks as guides to extend each ray backward. The rays will all intersect at the filament, and you will measure the distance between the filament and the center of your ray table.
8. Remove the paper from the ray table and tape it into your lab journal, making sure that you have adequate room. Use a pencil and straightedge to extend each of the rays. Trace them back to their common point of intersection. Label the filament and the center of the Ray Table on your diagram.
9. Measure the distance between your reference mark and the point of intersection of the rays.
10. Use the metric scale on the Optics Bench to measure the distance between the filament and the center of the Ray Table directly (see the note in Figure 2.)
11. How well do your measurements in Steps 9 and 10 agree? Comment on why they may not agree exactly.

Note: One of the key ideas that this experiment illustrates is the ability for us to trace light rays to their origin or apparent origin. This concept will prove most useful in future experiments.

Part II Color

Purpose: To gain an understanding of the color composition of white light. To investigate reflection and transmission of light when it illuminates a colored, but transparent medium.

Apparatus: Optics Bench, Light Source, Ray Table and Base, Component Holder, Ray Table Component Holder, Slit Plate, Slit Mask, Cylindrical Lens, Viewing Screen, Colored Filters (3).

Introduction: Early investigators assumed that light, in its purest, simplest form is white, and that refractive materials (transparent media, like lenses, water, and colored glass) alter the characteristics of the white light to create the various colors observed. Sir Isaac Newton was the first to show that light, in its simplest form, is the sum of many colors, and that refractive materials merely separate the various colors. He used this idea to help explain the colors of objects.

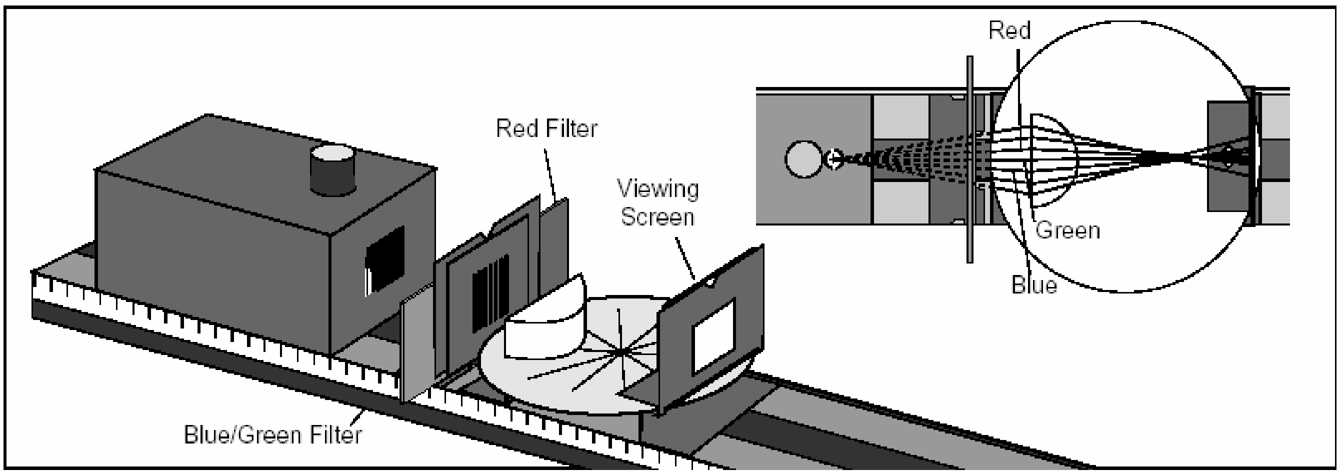

Figure 3 Experimental set-up for adding three colored rays.

Procedure: Set up the equipment as shown in Figure 3, and turn on the Light Source. Darken the room enough so the light rays on the Ray Table are easily visible.

Adding Three Colored Rays

Note carefully how the Component Holder between the Light Source and Ray Table supports the Red Filter and Blue/Green Filter on one side, and the Slit Plate on the other side. Align the Filters and Slit Plate so that the three central rays are each a different color. Arrange the Cylindrical Lens so that the three central light rays (one red, one green, and one blue) intersect at precisely the same point on the Ray Table. Slowly move the Viewing Screen toward this point of intersection (you'll have to remove it from its component holder).

1. What color of light results when red, green, and blue light are mixed? How does this support Newton's theory?

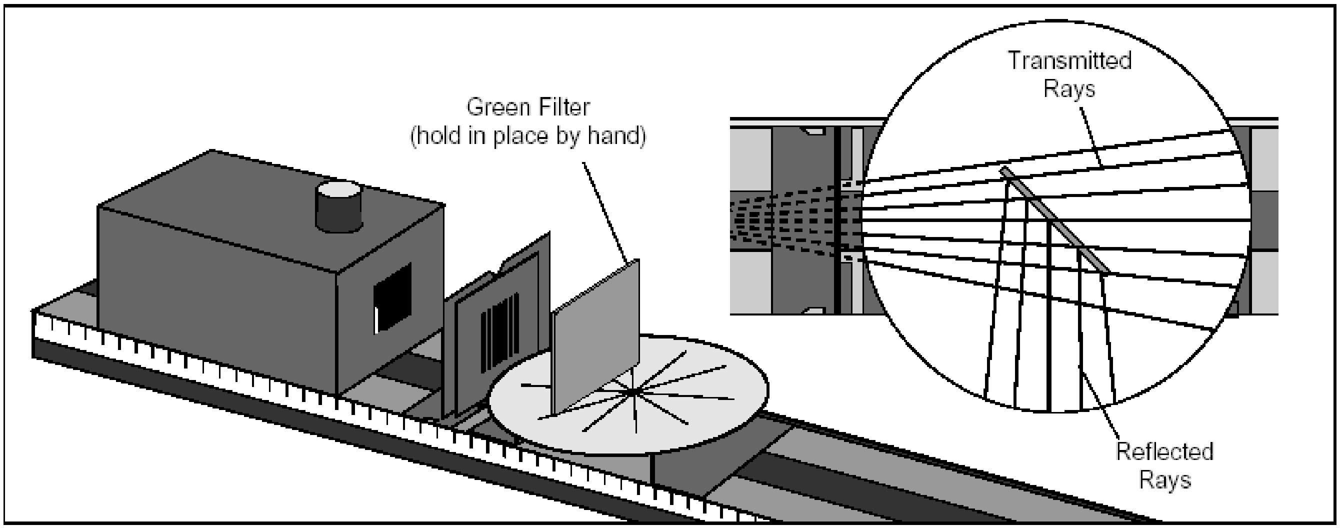

Figure 4 Experimental set-up for observing reflected and transmitted color.

The Colors of Objects
Set up the equipment as shown in Figure 4.

2. Observe the light rays that are transmitted and reflected from the Green Filter. The transmitted rays can easily be seen on the Ray Table. What color are the transmitted rays? The reflected rays are less intense. To observe the reflected rays, lower your head until you can look directly along their paths. What color are the reflected rays? Are there different colors reflected by the front side and back side of the Filter? Which side reflects which color?
3. Place the Red Filter behind the Green Filter (so the light passes first through the Green Filter and then through the Red Filter) and hold the Filters together as one unit. What color are the transmitted rays now? Lower your head and look into the Green Filter, along the reflected rays. What colors are the reflected rays now? Separate the two Filters slightly, and lean them at slightly different angles so that you can clearly see rays reflected from each Filter. What color are the rays reflected from the front and back surfaces of the Green Filter, and what color are the rays reflected from the front and back surfaces of the Red Filter?
4. Place the Blue Filter in front of the Slit Plate so the incident rays are blue. Let these rays pass through the Green Filter only. What color are the transmitted rays? What colors are the reflected rays now? Based on your observations, what makes the Green Filter appear green?

Part III Polarization

Purpose: To investigate the effect of polarization on the propagation of light by using Polaroid filters. To observe polarization due to reflection, and the effect on polarization when light is incident upon a transparent medium at Brewster's Angle.

Apparatus: Optical Bench, Light Source, Polarizers (2), Component Holders (3), Ray Table and Base, Ray Table Component Holder, Cylindrical Lens, Crossed Arrow Target, Slit Plate, Slit Mask.

Introduction: Light is a transverse wave; that is, the electromagnetic disturbances that compose light occur in a direction perpendicular to the direction of propagation (see Figure 5). Polarization, for light, refers to the orientation of the electric field in the electromagnetic disturbance. The magnetic field is always perpendicular to the electric field. Figure 5(b) and Figure 5(c) show vertical and horizontal polarization, respectively. Figure 5(d) depicts random polarization, which occurs when the direction of polarization changes rapidly with time, as it does in the light from most incandescent light sources.

Your optics equipment includes two Polarizers, which only transmit light that is plane polarized along the plane defined by the 0 and 180 degree marks on the Polarizer scales. Light that is polarized along any other plane is absorbed by the Polaroid material. Therefore, if randomly polarized light enters the Polarizer, the light that passes through is plane polarized. In this experiment, you will use the Polarizers to investigate the phenomena of polarized light.

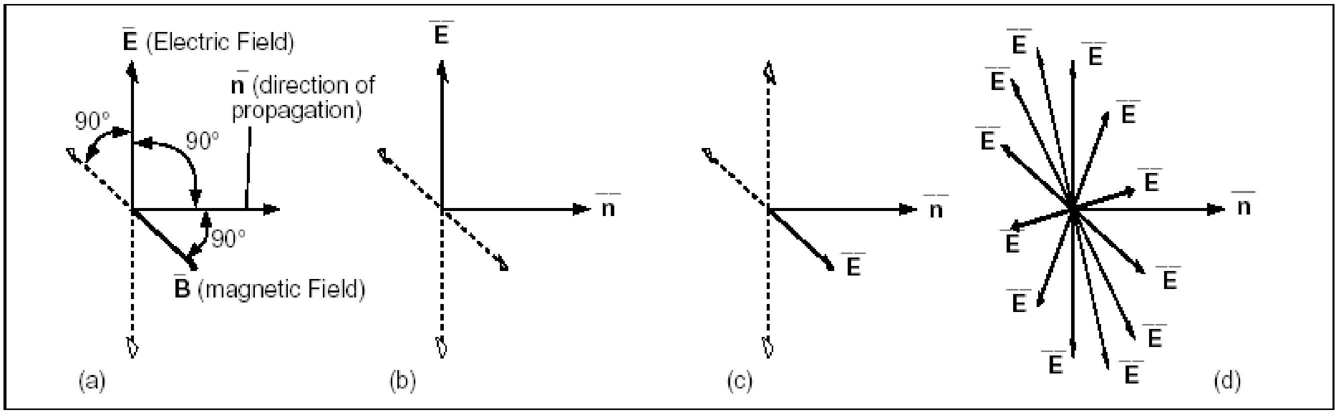

Figure 5 Polarization of light. Light propagating to the right can be vertically polarized as in (b), horizontally polarized as in (c), or randomly polarized as in (d). The direction of polarization is determined by the direction of the electric field and (a) shows the relationships between the direction of the electric field, the magnetic field and the propagation of light.

Procedure:

The Effect of Polarization on the Propagation of Light

1. Set up the equipment as shown in Figure 6. Turn the Light Source on and view the Crossed Arrow Target with both Polarizers removed, by lowering your head at the far end of the Optics Bench and looking along its length toward the light source. Note the intensity of the light.
2. Place Polarizer A on the Component Holder and look through Polarizer A alone. Rotate the Polarizer while viewing the target. Does the target seem as bright when looking through the Polarizer as when looking directly at the target without any Polarizer? Why? Is the light from the Light Source plane polarized? How can you tell?
3. Align Polarizer A so it transmits only vertically polarized light. Place Polarizer B on the other Component Holder. Looking through both Polarizers, rotate Polarizer B. For what angles of Polarizer B is a maximum of light transmitted? For what angles is a minimum of light transmitted? Is it possible to find angles for which no light passes through Polarizer B? If so, what are the angles?

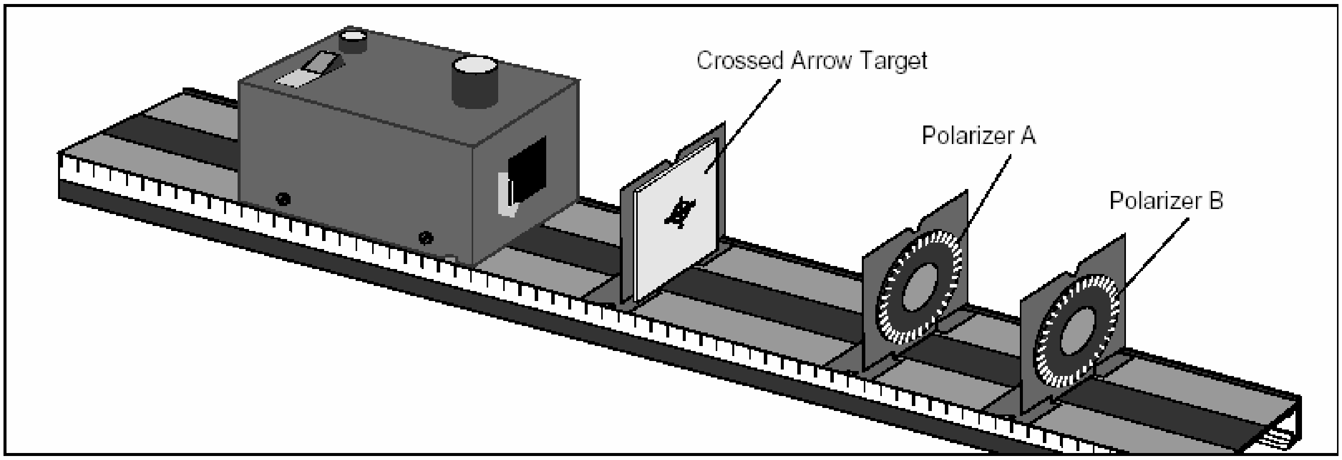

Figure 6 Experimental set-up for investigation of polarization of light.

Polarization by Reflection: Brewster's Angle

4. Set up the equipment as shown in Figure 7. Adjust the components so a single ray of light is incident on the Cylindrical Lens at the center of the Ray Table. Notice the rays that are produced as the incident ray is reflected and refracted at the flat surface of the Cylindrical Lens. (The room must be reasonably dark to see the reflected ray.)
5. Rotate the Ray Table until the angle between the reflected and refracted rays is 90°. Arrange the Ray Table Component Holder so it is in line with the **reflected** ray. Look through the Polarizer at the filament of the light source (as seen reflected from the Cylindrical Lens), and rotate the Polarizer slowly through all angles. Is the reflected light plane polarized? If so, at what angle from the vertical is the plane of polarization?
6. Observe the reflected image for other angles of reflection. What do you observe when you rotate the Polarizer now? Is the reflected light polarized when the reflected ray is not at an angle of 90° with respect to the refracted ray? How can you tell?

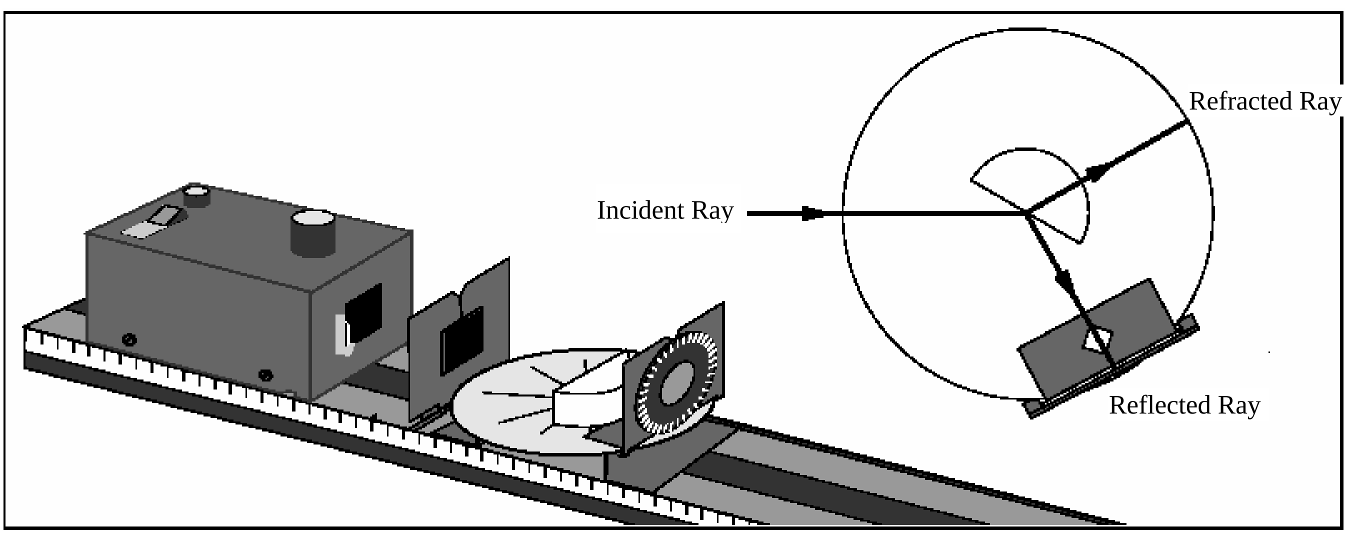

Figure 7 Experimental set-up for investigating polarization of light by reflection from a transparent medium.