Optics Experiment 4 – Dispersion
Total Internal Reflection

Dispersion is a refractory phenomenon that occurs because as light slows down and bends upon entering a denser transparent medium from a less dense transparent medium it slows down and bends proportional to its wavelength. This results in splitting light beams, which normally consist of many colors superimposed, into several beams of elemental color as they pass from air into water or a block of glass or plastic or other transparent medium. White light, for example, consists of all wavelengths of light combined with equal intensity and the splitting of a beam of white light from the sun, for instance, through a raindrop results in the production of a rainbow of colors.

Total internal reflection occurs when a beam of light originates in a transparent medium of greater density and attempts to move into a medium of lesser density (water into air, for instance). In certain circumstances the beam of light is unable to cross the optical boundary between the two materials and total internal reflection is the result.

Equipment needed

- Optics bench
- Ray table and base
- Slit plate
- Ray table component holder
- Acrylic cylindrical lens
- Viewing screen
- Component holder
- Slit mask

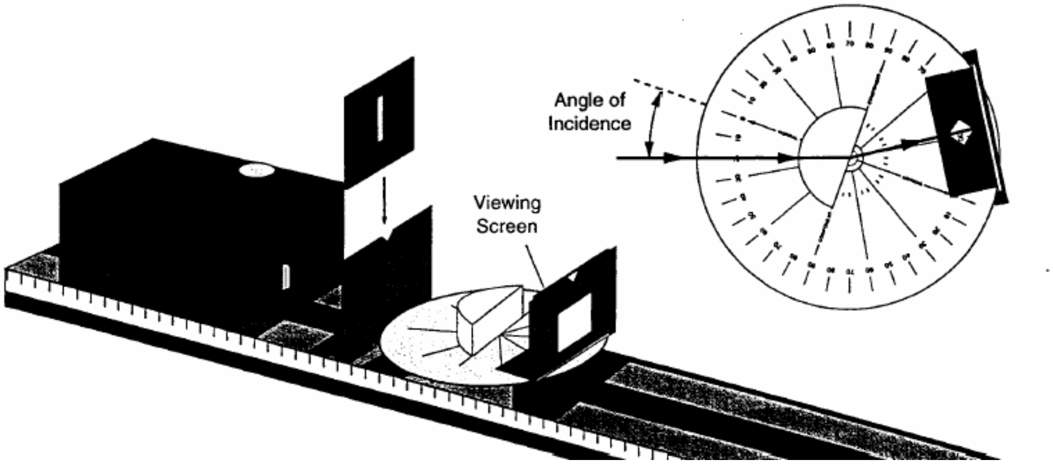


Figure 1 (Courtesy of PASCO)

Procedure

Setup as in Fig 1. Adjust the components of the optical system so that a single ray of white is incident upon the curved surface of the acrylic cylindrical lens.

Position the ray table so the angle of incidence of the ray striking the flat surface of the lens (after passing through the lens) is zero degrees. Adjust the ray table component holder so the refracted ray is visible on the viewing screen. Slowly increase the angle of incidence and as you do observe the refracted ray on the viewing screen.

1. At what angle of refraction do you first notice a separation of color in the refracted ray? At what angle of refraction is the color separation a maximum?

2. What colors are present in the refracted ray? Write down each color in the order of minimum to maximum angle of refraction.

3. Using red and blue rays, measure the index of refraction of the acrylic in the lens for red and blue light. ($n_{acrylic} \sin\theta_{acrylic} = n_{air} \sin\theta_{air}$).

4. Are the indices of refraction different for acrylic in red and blue light?

Notice that not all of the light in the incident ray is refracted across the flat boundary with air. A portion of the light is reflected and remains within the lens.

1. From which surface of the lens does the reflection primarily occur?

2. Is there a reflected ray for all angles of incidence? (Use the viewing screen to detect faint rays.)

3. Are the angles for the reflected ray consistent with the law of reflection?

4. Is there a *refracted* ray for all angles of incidence?

5. How does the intensity of the reflected and refracted rays vary with the angle of incidence?

6. At what angle of refraction is all of the light reflected (no refracted ray)? This is known as the *critical angle*, and is particular to the materials on each side of the optical boundary (in this case acrylic and air).

Questions

1. What does the index of refraction for a transparent material represent?

2. What are the conditions for total internal reflection?

Production of a Rainbow

A rainbow is a common natural phenomenon that involves both dispersion and total internal reflection.

Recall, from your experience, the conditions that exist when viewing a rainbow. Normally rainbows occur after a storm has passed when the sun has emerged from the clouds. The sun is always at your back and rain is always ahead of you.

As white light from the sun enters an individual raindrop it is refracted and separated into different colors - each traveling a different path through the raindrop because the index of refraction or the raindrop is different for each color of light. As the different colored light beams reach the boundary between the raindrop and air at the back of the raindrop total internal reflection occurs due to the angle of incidence being greater than the critical angle. The light beams travel back across the raindrop and intersect the water/air boundary on the other side of the raindrop at less than the critical angle. They cross this boundary this time and are refracted again as they enter the air.

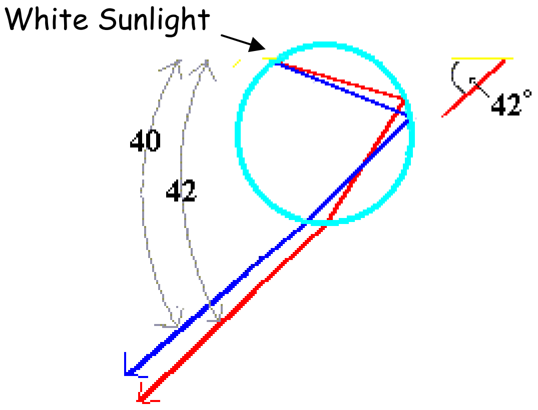


Figure 2

Optics Experiment 5
Converging Lens Image and Object Relationships

In optical terms an *object* is anything one is looking at through a lens or in a mirror. The *image* is what the lens or mirror produces (often an optical system produces an image on the retinal plane within your eye, but this is not always the case). The *focal length* of a lens or a mirror is a parameter commonly used to identify lenses by radius of curvature. A converging lens is a common type of lens having two convex surfaces.

Given an object and a lens or mirror of any shape or material one may determine the location of the image the lens or mirror forms from the lens/mirror based on the laws of refraction and reflection. This, however, is frequently complex and cumbersome. In the case of thin lenses or mirrors with spherical surfaces the relationship between object distance, image distance and focal length is:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad \text{The lens equation}$$

The magnification of the image is given by:

$$m = -\frac{d_i}{d_o}$$

In this procedure you will empirically explore these relationships.

Equipment needed

- Optics bench
- 75mm Focal length convex lens
- Component holders (3)
- Viewing screen
- Light source
- Crossed arrow target

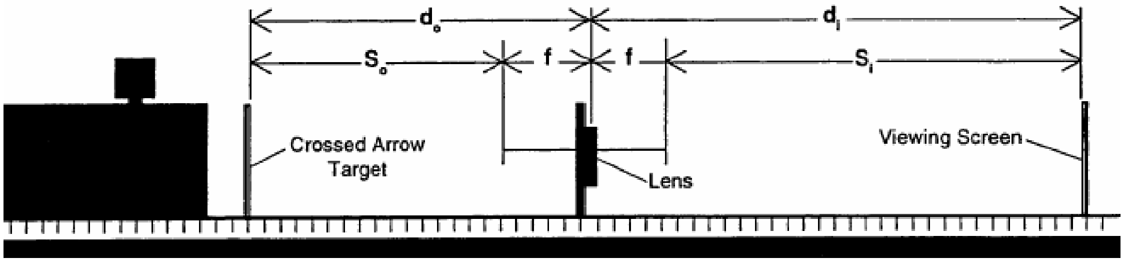


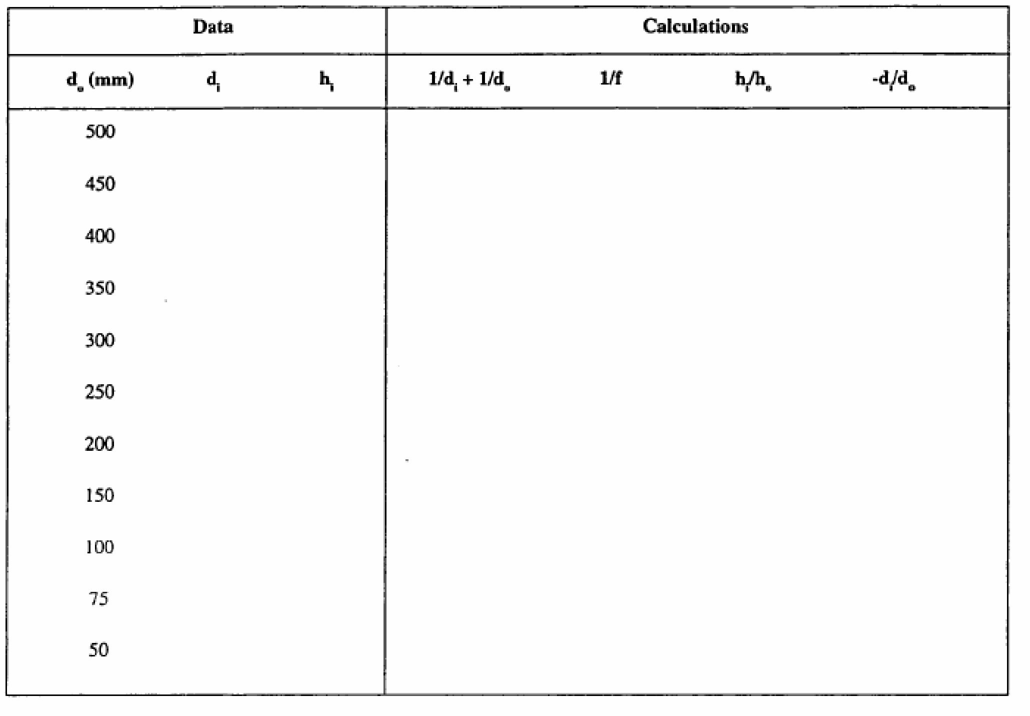
Figure 3 (Courtesy of PASCO)

Procedure

Setup as in Fig 3. Turn on the light source and slide the lens toward or away from the crossed arrow target as needed to focus the image of the target sharply onto the viewing screen.

1. Is the image a magnified or reduced version of the object?
2. What is the orientation of the image in space with respect to the object, i.e., is the image inverted or upright?
3. Based on the lens equation $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$ what would happen to the image distance, d_i, if you increased the object distance, d_o, even further?
4. What would happen to the image distance if the object distance were very, very large? Hint: what is the quantity $\frac{1}{\infty}$ equal to?
5. Using your answer to question 4 rearrange the lens equation and compute the focal length of the lens.

Reproduce the table below in your lab notebook. Incrementally set the object distance (in millimeters) to the values given. At each distance locate the image, measure the image distance and measure the height of the image. The height of the object is the height of the arrow on the arrow target.



Data			Calculations			
d_o (mm)	d_i	h_i	$1/d_i + 1/d_o$	$1/f$	h_i/h_o	$-d_i/d_o$
500						
450						
400						
350						
300						
250						
200						
150						
100						
75						
50						

Table 1 (Courtesy of PASCO)

6. Are your results in agreement with the lens equation? If not why?

7. For what values of the object distance were you unable to focus an image onto the screen? Use the lens equation to explain why.

Questions

1. For a lens of focal length *f*, what value of object distance would yield an image with a magnification of one?

2. Is it possible to obtain a non-inverted image with a converging spherical lens? (Hint: what happens when the object is closer than the focal length) Explain.

3. For a converging lens of focal length *f*, where would you place the object to produce an image as far away from the lens as possible? How large would the image be with respect to the object?

Optics Experiment 6 - Light and Color

Early investigations of light assumed that light in its purest form is white and that refractive materials alter the characteristics of the white light to create the various colors. Newton was the first to show that light in its simplest form is colored and refractive materials merely separate the various colors which are natural components of white light. He used this idea to help explain the colors of objects.

Equipment needed

- Optics bench
- Slit plate
- Component holder
- Cylindrical lens
- Colored filters (3)
- Ray table and base
- Ray table component holder
- Slit mask
- Viewing screen

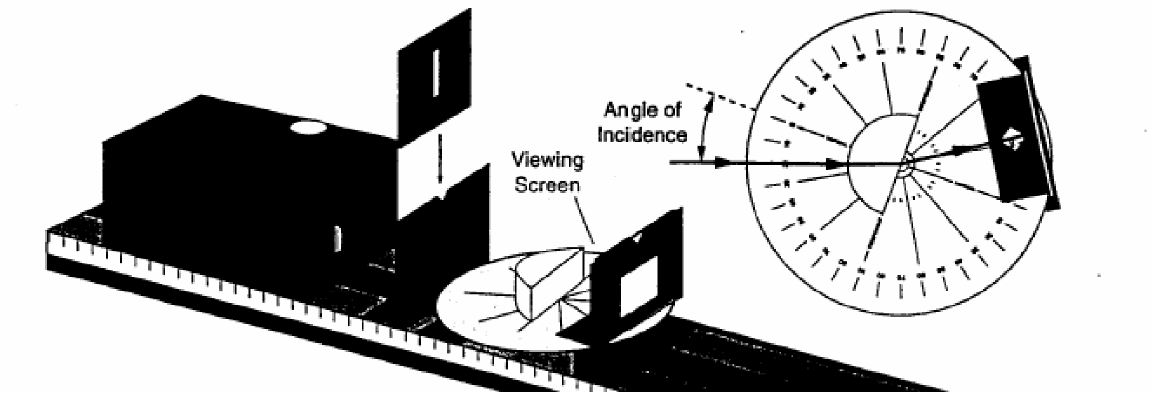


Figure 4 (Courtesy of PASCO)

Setup as in Fig 4. Adjust the equipment so a single ray of light passes through the center of the ray table. Rotate the table slowly to increase the angle of incidence of the light ray. Notice the refracted ray on the viewing screen and the dispersion and color separation at large angles of refraction. Do your observations appear to support Newton's theory? Explain.

To investigate further setup the equipment as in Fig 5. Arrange the cylindrical lens so that the three central light rays (one red, one green, and one blue) intersect precisely at the same point on the ray table. Move the viewing screen slowly toward the point of intersection (you'll have to remove it from its component holder).

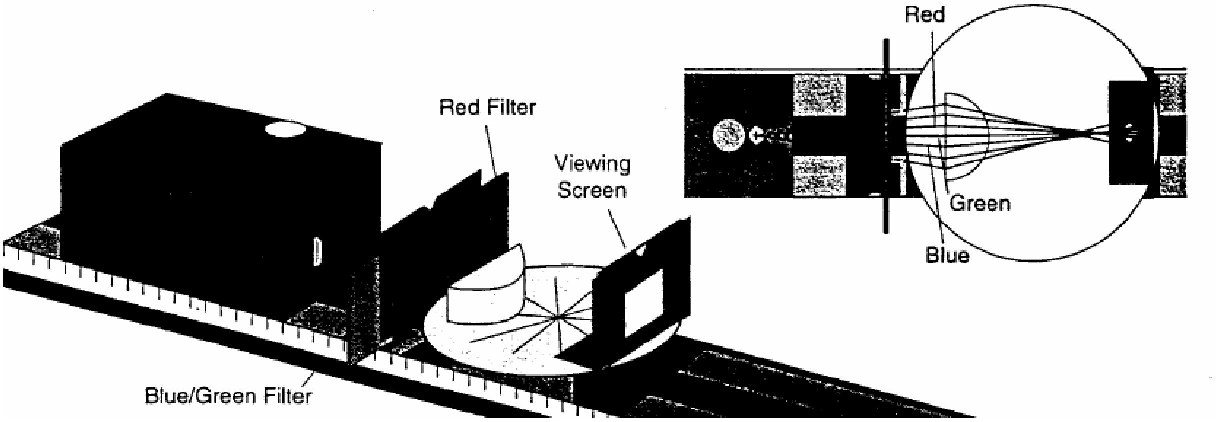


Figure 5 (Courtesy of PASCO)

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

Now setup the equipment as in Fig. 6. Observe the light rays that are transmitted and reflected from the green filter.

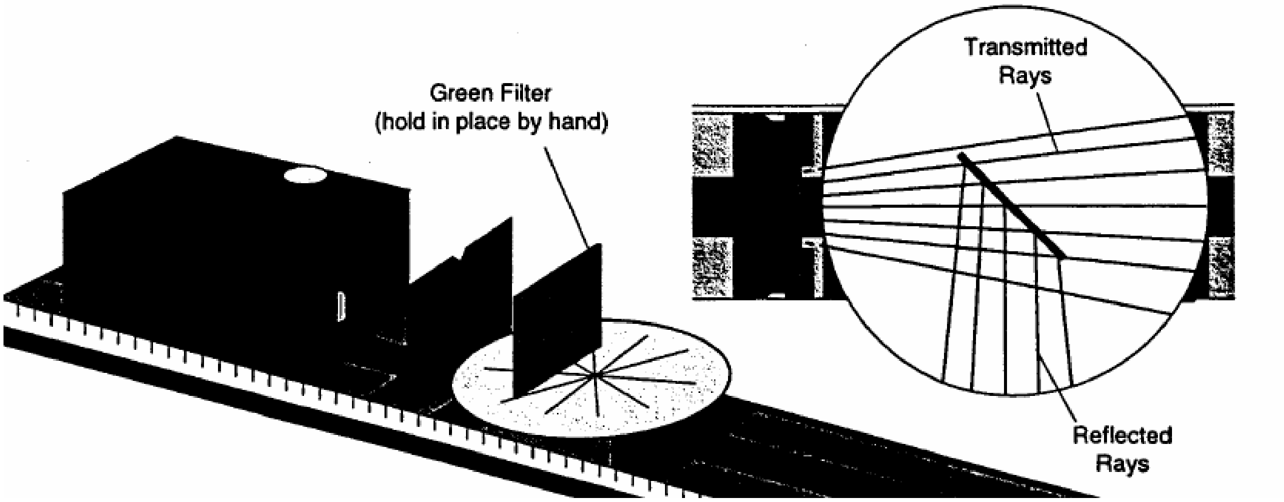


Figure 6 (Courtesy of PASCO)

1. What color are the transmitted rays? What color are the reflected rays?

Place the red filter behind the green filter (so the light passes through the green filter then the red). Look into the green filter.

2. What color are the reflected rays now? Which rays are reflected from the front surface of the green filter and which are reflected from the front surface of the red filter?

Place the blue filter over the light source aperture so the incident rays are blue. Let these rays pass only through the green filter.

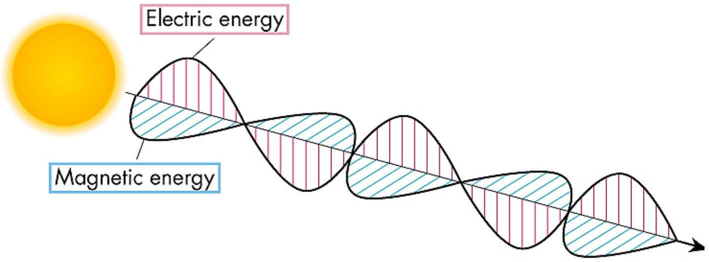
3. What color are the reflected rays?

Based on your observations what makes the green filter appear green?

In general, the color of objects is a complex subject. The sky is blue, a blade of grass green (or brown depending on its access to moisture), a snowflake white all for slightly different reasons. Reflection, dispersion, scattering, absorption all play a role in determining the colors of everyday objects.

Optics Experiment 7 - Polarization

Light is a transverse electromagnetic wave. A transverse wave is characterized by wave oscillation in a direction that is perpendicular to the direction the wave is traveling in space (Fig 7a). In the case of light, both the electric and magnetic fields oscillate in directions that are perpendicular to the direction the light is traveling.



Polarization of light is manipulation of the orientation of the electric field component of a light wave as it travels through space (the magnetic field is always perpendicular to the electric field and is generally ignored in discussions of polarization). Figs. 7b and 7c show vertical and horizontal polarization respectively. These patterns are known as plane polarization because all components of the electric field except for those vibrating in a certain plane have been suppressed.

Figure 7d represents random polarization which occurs when the direction of polarization changes rapidly with time as does the light from most incandescent light sources. Most normal light beams have this rapidly changing polarization and are generally referred to as unpolarized.

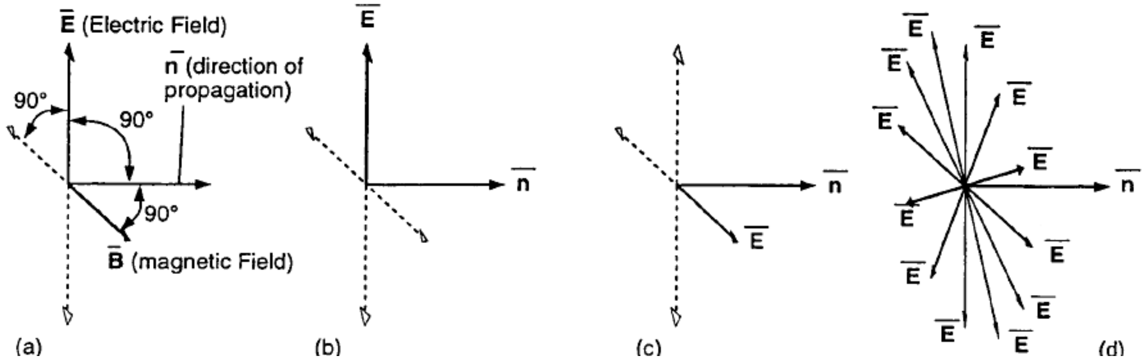


Figure 7 (Courtesy of PASCO)

Equipment needed

- Optics bench
- Polarizer (2)
- Ray table and base
- Cylindrical lens
- Slit plate
- Light source
- Component holders (3)
- Ray table component holder
- Crossed arrow target
- Slit mask

The optics setup includes two polarizing filters which will transmit only light that oscillates in the horizontal and vertical directions. You will use these polarizing filters to investigate the properties of polarized light.

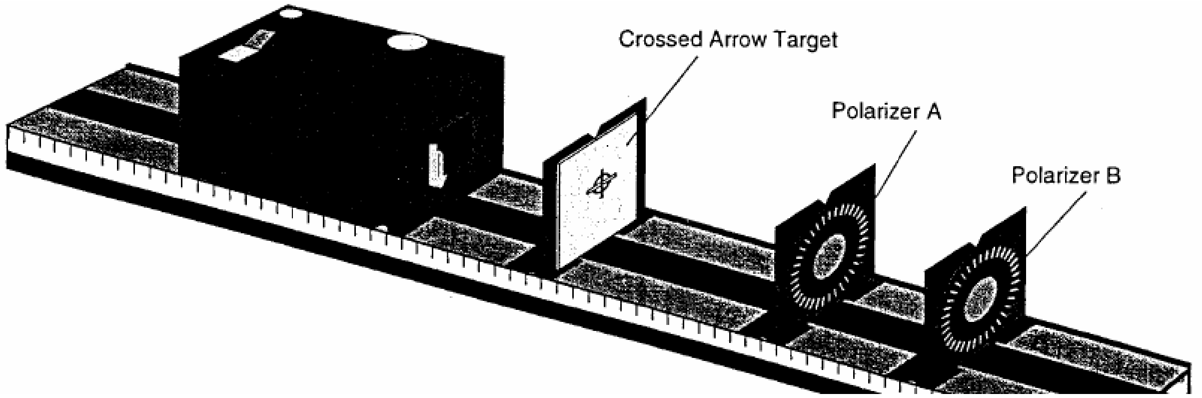


Figure 8 (Courtesy of PASCO)

Procedure

Set your lab equipment as shown in Fig. 8 above. Turn on the light source and view the crossed arrow target with both polarizing lenses removed. Now place polarizer A on the component holder. Rotate the polarizer while viewing the target.

1. Does the target seem as bright when looking through the polarizer as when looking directly at the target? Why?

2. Is the light from the light source plane polarized? How can you tell?

Align polarizer A so that it transmits only vertically polarized light. Replace polarizer B on the other component holder. Looking through both polarizers, rotate polarizer B.

3. For what angles of polarizer B is a maximum of light transmitted? For what angles is there a minimum transmitted?

Polarization by Reflection: Brewster's Angle

Setup the equipment as shown in Fig. 9. Adjust the components so a single ray of light passes through the center of the ray table. Notice the rays produced as the incident ray is reflected and refracted at the flat surface of the cylindrical lens. The room must be fairly dark to see the reflected ray.

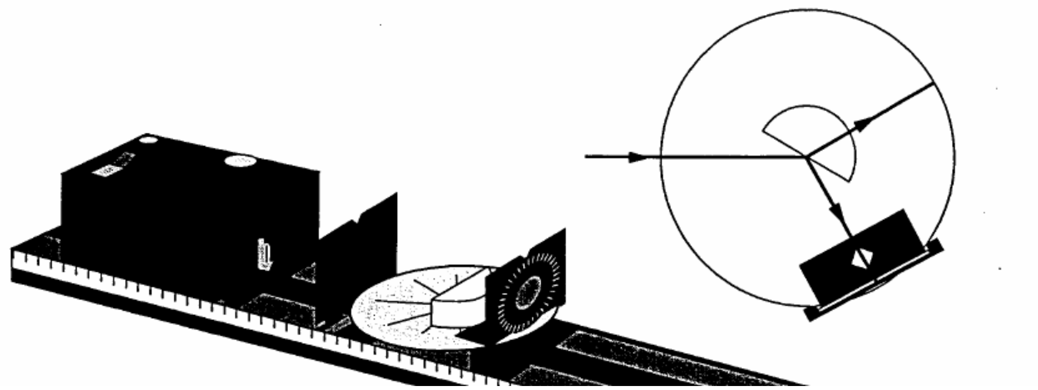


Figure 9 (Courtesy of PASCO)

Rotate the ray table until the angle between the refracted and reflected rays is 90 degrees. 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.

1. Is the reflected light plane polarized? If so at what angle from the vertical is the plane of polarization?

Observe the reflected image for other angles of reflection.

2. Is the light plane polarized when the reflected ray is not at an angle of 90 degrees with respect to the refracted ray? Explain.

Polarization of visible light is an effect exploited to produce things such as polarizing sunglasses (what components of light do you think are suppressed by the filters in these glasses?) but also occurs naturally. Most of the light visible at very high altitudes is highly polarized due to scattering.