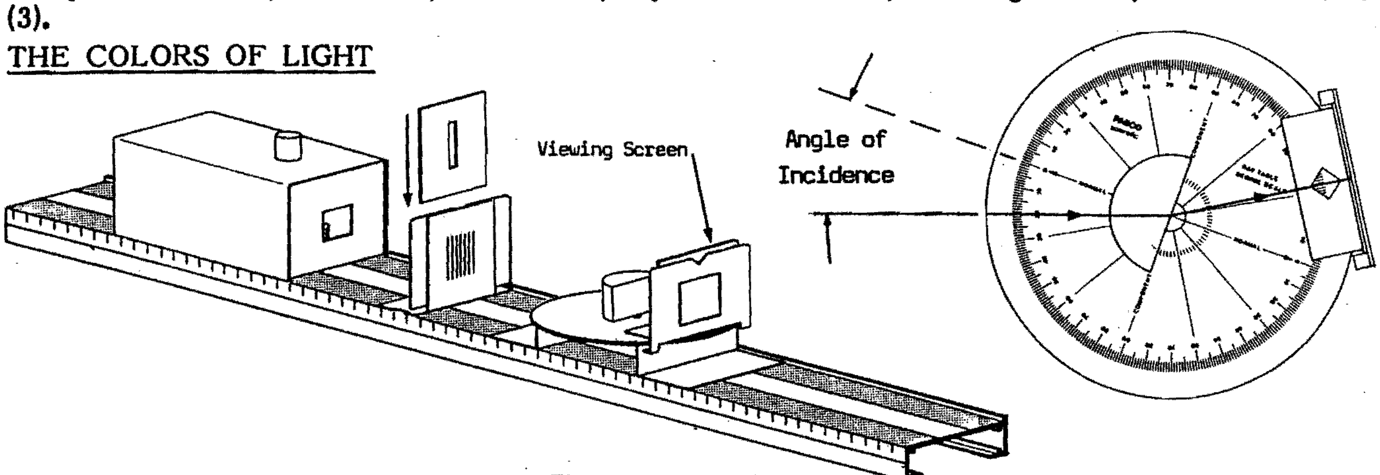
Experiment 8: Light and Color

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

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

THE COLORS OF LIGHT



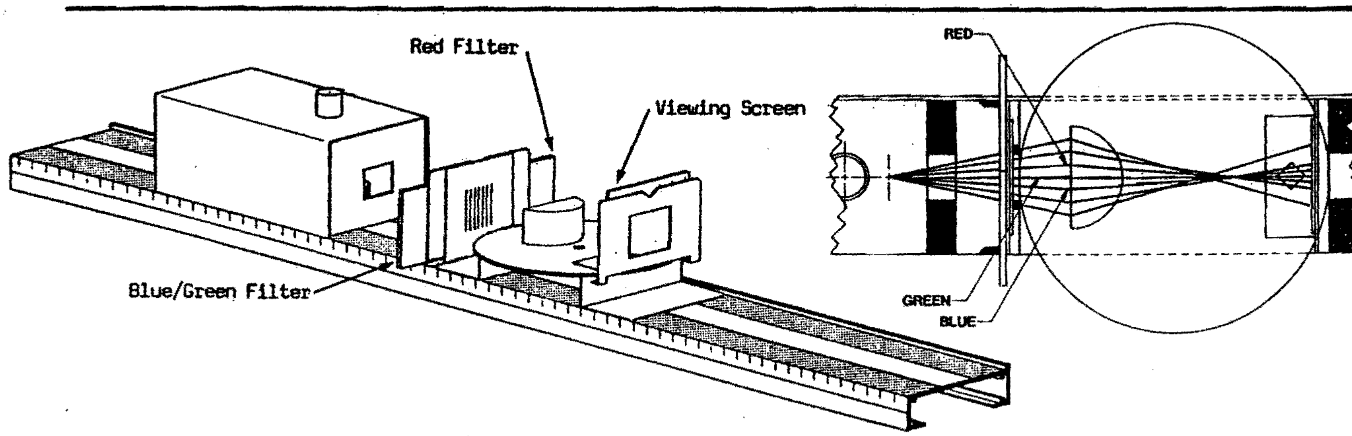
Equipment Setup

Setup the equipment as shown above. Slowly rotate the Ray Table to increase the angle of incidence of the light ray. Examine the refracted ray on the Viewing Screen. Notice the color separation at large angles of refraction.

1. Do your observations support Newton's theory? Explain.

____

____.



Mixing Colored Light

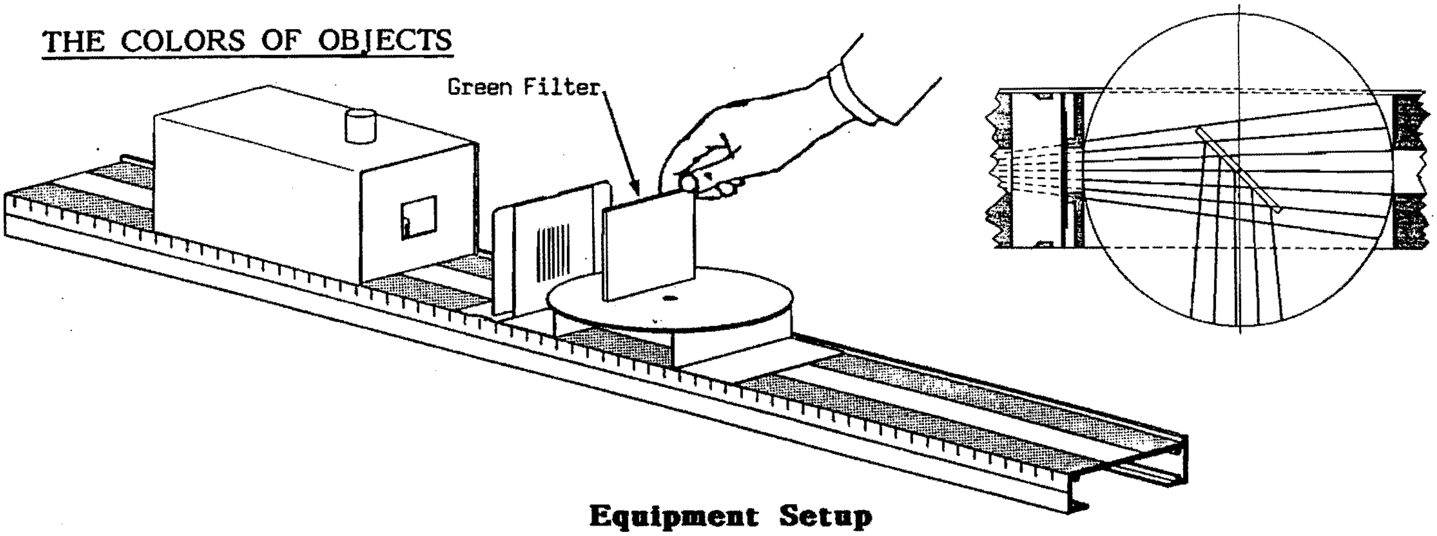
To investigate further, setup the equipment as shown above. Arrange the Cylindrical Lens so that the three central light rays (one red, one green, and one blue) intersect at precisely the same point on the Ray Table. Move the Viewing Screen slowly toward this point of intersection.

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

____

____.

THE COLORS OF OBJECTS



Equipment Setup

Setup the equipment as shown above. Observe the light rays that are transmitted and reflected from the Green Filter.

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

____.

Place the Red Filter behind the Green Filter, and look into the Green Filter.

2. What colors of reflected rays do you see 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 through the Green Filter only.

3. What colors are the reflected rays now?______________________________.

4. Based on your observations, what makes the Green Filter appear green?

____

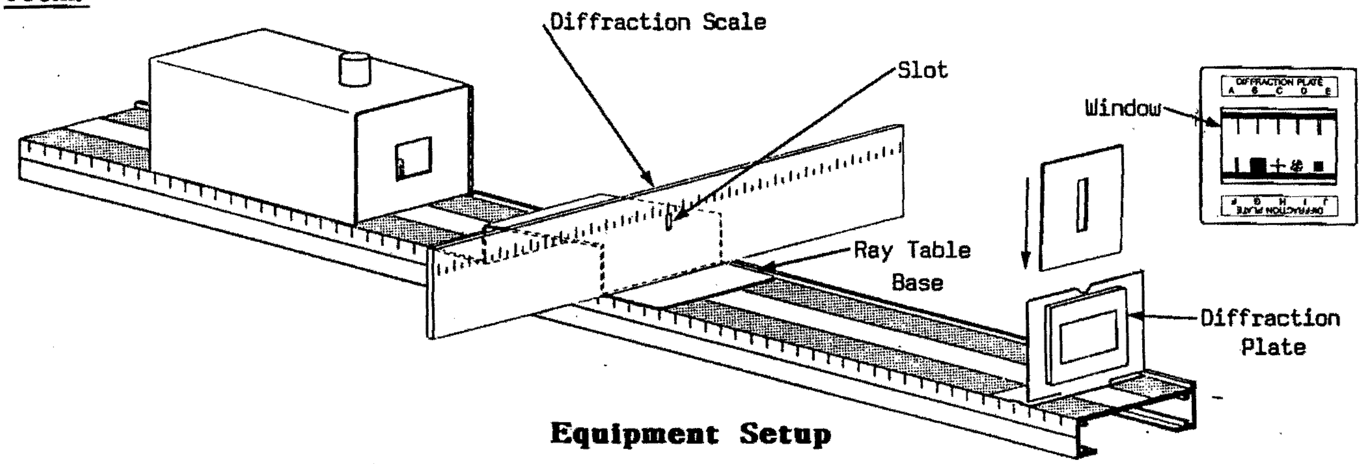
____.

Experiment 9: Two-Slit Interference

What is light? There may be no complete answer to this question. However, in certain circumstances, light behaves exactly as if it were a wave. In fact, in this experiment you will measure the wavelength of light, and see how that wavelength varies with color.

In two-slit interference, light falls on an opaque screen with two closely spaced, narrow slits. As Huygen's principle tells us, each slit acts as a new source of light. Since the slits are illuminated by the same wave front, these sources are in phase. Where the wave fronts from the two sources overlap, an interference pattern is formed.

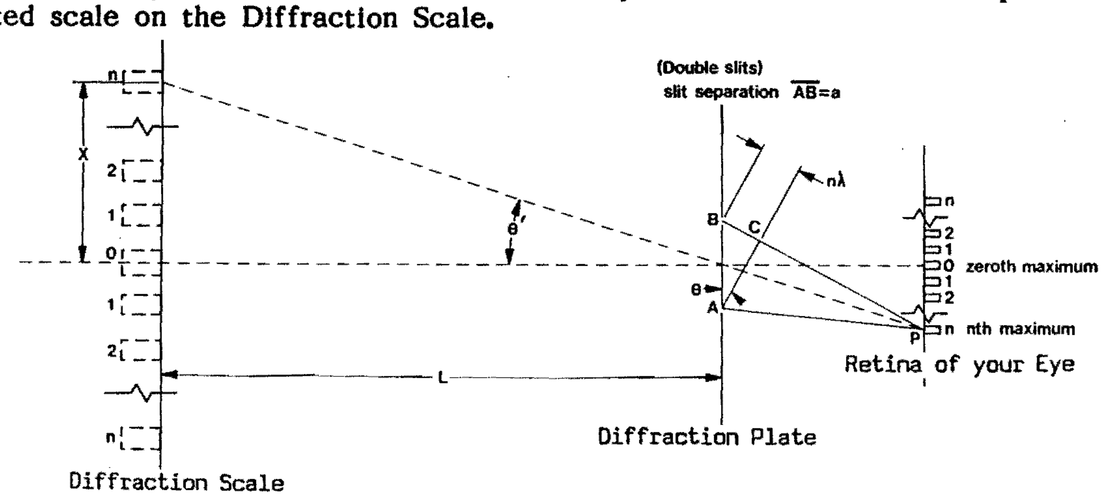
EQUIPMENT NEEDED: Optics Bench, Light Source, Diffraction Plate, Diffraction Scale, Ray Table Base, Slit Mask, Component Holder, Color Filters (3). Perform in a well-lighted room.



Equipment Setup

Setup the Equipment as shown above. The Slit Mask should be centered on the Component Holder. While looking through the Slit Mask, adjust the position of the Diffraction Scale so you can see the filament of the Light Source through the slot in the Diffraction Scale.

Attach the Diffraction Plate to the other side of the Component Holder, as shown. Center pattern D, with the slits vertical, in the aperture of the Slit Mask. Look through the slits. By centering your eye so that you look through both the slits and the window of the Diffraction Plate, you should be able to see clearly both the interference pattern and the illuminated scale on the Diffraction Scale.



Geometry of Two-Slit Interference

The essential geometry of the experiment is shown above. At the zeroth maxima, light rays from slits A and B have traveled the same distance, so they are in phase and interfere constructively. At the first order maxima (on the left) light from slit B has traveled one wavelength farther than light from slit A, so constructive interference occurs at this position as well.

At the nth order maxima, the light from B has traveled n wavelengths farther than the light from A. In the diagram, the line AC is constructed perpendicular to the line PB. Since the slits are very close together (in the experiment, not the diagram), lines AP and BP are nearly parallel. Therefore, to a good approximation, AP = CP. This means that, for constructive interference to occur at P, it must be true that $BC = n\lambda$.

From right triangle ACB, $BC = a \sin\theta$; therefore, $a \sin\theta = n\lambda$. The spacing between the slits, a, is listed in the Equipment section of this manual. Therefore, you need only measure for a particular n to determine the wavelength of light.

To measure θ, notice that the dotted lines in the illustration show a projection of the interference pattern onto the Diffraction Scale (as it appears when looking through the slits). Notice that $\theta' = \arctan x/L$. Assuming PA and PB are parallel, $\theta' = \theta$. Therefore, $\theta = \arctan x/L$; and $\underline{a \sin(\arctan x/L) = n\lambda}$.

Looking through the pair of slits (pattern D) at the Light Source filament, make measurements to fill in the following table. Alternately place the Red, Green, and Blue color filters over the Light Source aperture to make the measurements for different colors of light. If you have time, make measurements with the other two-slit patterns as well (patterns E and F).

Perform the calculations shown to determine the wavelength of Red, Green, and Blue Light.

	DATA				**CALCULATIONS**
Color	n	a	X	L	$(a/n) \sin(\arctan X/L) = \lambda$
RED					
GREEN					
BLUE					

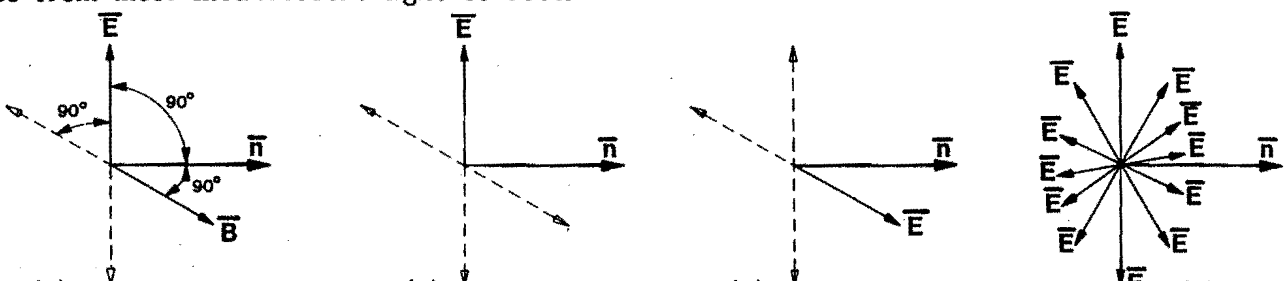
ADDITIONAL QUESTIONS

1. Assume, in the diagram showing the geometry of the experiment, that AP and BP are parallel. Show that $\theta = \theta'$.

2. Suppose the space between the slits was smaller than the wavelength of light you were trying to measure. How many orders of maxima would you expect to see?

Experiment 10: Polarization

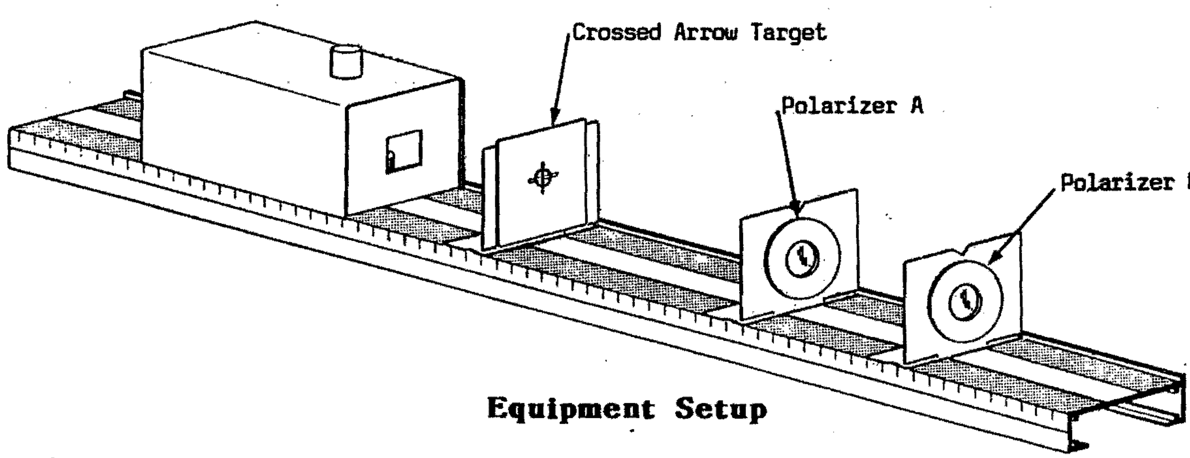
Light is a transverse wave; that is, the electromagnetic disturbances that compose light occur in a direction perpendicular to the direction of propagation (see Figure (a) below). Polarization, for light, refers to the orientation of the electric field in the electromagnetic disturbance--the magnetic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



Polarization of Light

Your optics equipment includes two Polarizers, which transmit only 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.

EQUIPMENT NEEDED: 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.



Equipment Setup

Setup the equipment as shown above. View the target with both Polarizers removed. Replace 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?

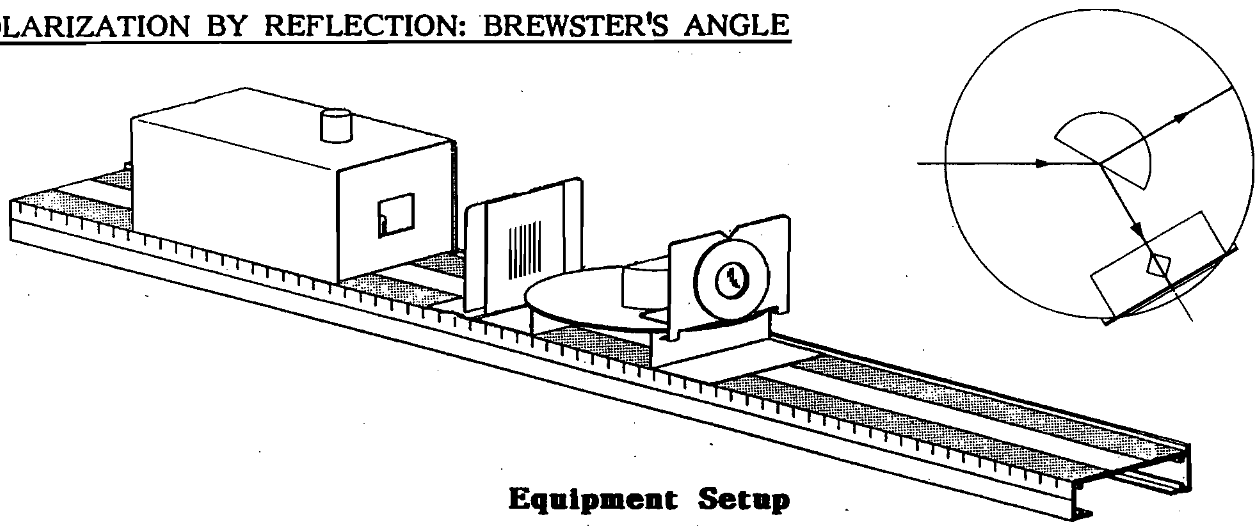
____.

Align Polarizer A so 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 a minimum of light transmitted?

____.

POLARIZATION BY REFLECTION: BREWSTER'S ANGLE



Equipment Setup

Setup the equipment as shown above. Adjust the components so a single ray of light passes through 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.)

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.

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° with respect to the refracted ray? Explain.

____

____.

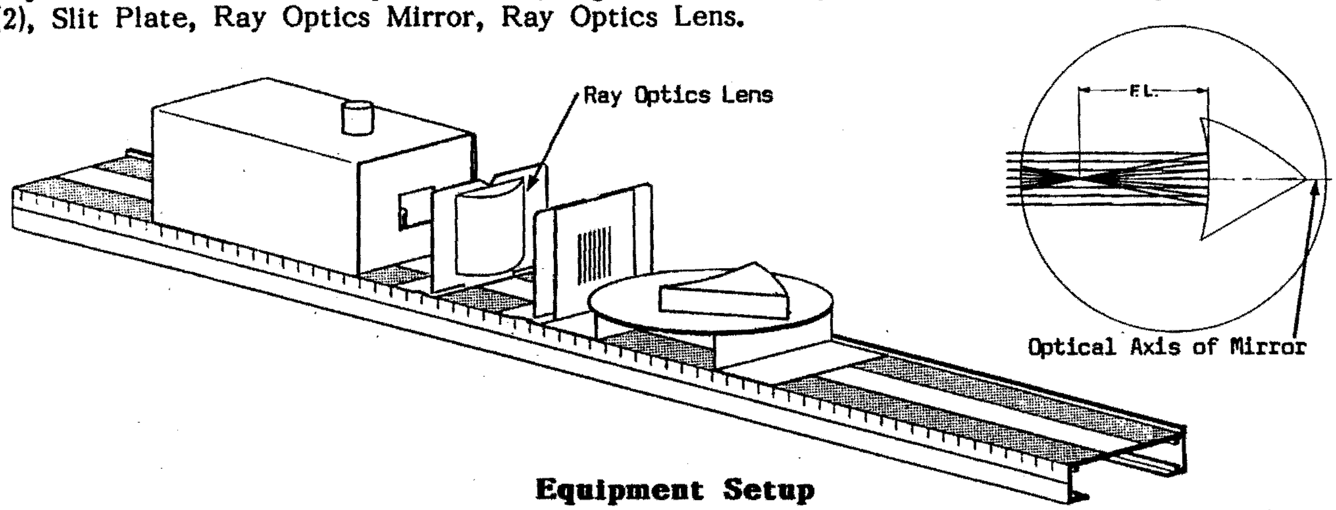
ADVANCED EXPERIMENTS

Experiment 11: Image Formation from Cylindrical Mirrors

Ray tracing techniques can be used to locate the image formed by reflection from any mirror of known shape. Simply think of the object as a collection of point sources of light. For a given point source, light rays diverging from it are reflected from the mirror according to the Law of Reflection. If the reflected rays intersect at a point, a real image is formed at that point. If the reflected rays do not intersect, but would if they were extended back beyond the mirror, a virtual image is formed which appears to be located at the point where the extended rays cross.

In this experiment, you will use the Ray Table to study the properties of image formation from cylindrical surfaces. The properties you will observe have important analogs in image formation from spherical mirrors.

EQUIPMENT NEEDED: Optics Bench, Light Source, Ray Table and Base, Component Holder (2), Slit Plate, Ray Optics Mirror, Ray Optics Lens.



Equipment Setup

Set up the equipment as shown above. Position the Ray Optics Mirror on the Ray Table so the rays are all reflected from the concave surface of the mirror.

FOCAL POINT

Adjust the position of the Ray Optics Lens to obtain parallel rays on the Ray Table. Adjust the mirror on the Ray Table so the incident rays are parallel to the optical axis of the mirror.

1. Measure F.L., the focal length of the concave cylindrical mirror.

   F.L. = ______________________________.

2. Use ray tracing techniques to measure the focal length of the convex cylindrical mirror. (Check your textbook if you have doubts about the sign conventions.)

   F.L. = ______________________________.

Adjust the position of the Light Source and the Ray Optics Lens so the rays cross at a point on the Ray Table, as shown below. (A blank, white sheet of paper placed over the Ray Table will help to see the rays.) Since rays diverge from this point, it can be used as an object. Place the convex side of the Ray Optics Mirror so that its focal point is coincident with the point where the Rays cross. Of course, with the mirror in this position, the rays are reflected and don't actually cross. The point where the rays did cross, though, can be considered a virtual object.

Virtual Object

3. Describe the reflected rays when a virtual object is positioned at the focal point of the convex mirror.

____.

IMAGE LOCATION

Remove the Ray Optics Lens. Move the Slit Plate, Ray Table, and concave mirror as far as possible from the Light Source.

1. Where is the image of the light bulb filament formed?

____.

2. How is image location affected as you move the mirror closer to the filament?

____.

3. Is an image still formed when the distance between the filament and mirror is less than the focal length of the mirror? If so, what kind?

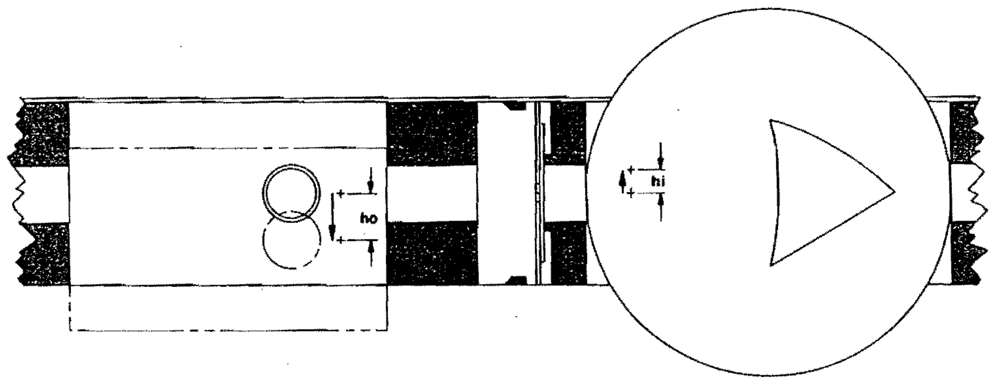
____.

4. Using the convex side of the mirror, can you obtain a real image of the Light Source filament? If so, how?

____.

MAGNIFICATION AND INVERSION

In the plane of the Ray Table, the filament of the Light Source acts as a point source. To observe magnification and inversion, an extended source is needed. As shown below, two positions of the Light Source filament can be used to define an imaginary arrow.



Magnification and Inversion

Position the filament of the Light Source first at the tail of the arrow, then at the tip of the arrow. Locate the image for each position. The height of the image arrow, h_o, divided by the height of the object arrow, h_i, is the magnification of the image.

Measure the magnification for several different distances between the light source and the mirror.

1. Qualitatively, how does the degree of magnification depend on the distance between the object and the mirror?

____

____.

2. Is the image inverted? Does image inversion depend on object location?

____.

<u>CYLINDRICAL ABERATION</u>

Cylindrical aberation is the distortion of the reflected image caused by imperfect focusing of the reflected rays. Place a blank sheet of paper over the Ray Table. Arrange the equipment so all the light rays are reflected from the concave surface of the mirror. Block all but two rays and mark the point of intersection. Do this for several pairs of rays.

1. Are all the rays focused at precisely the same point?

____.

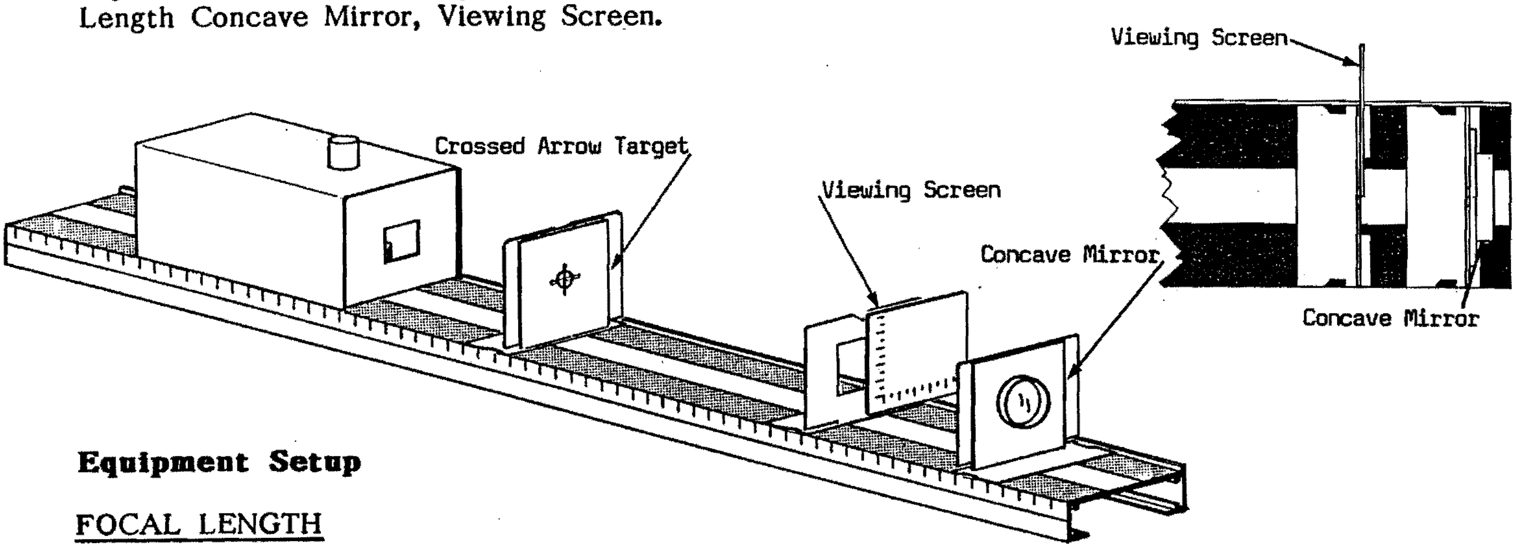
2. How would you alter the shape of the cylindrical lens to reduce the amount of cylindrical aberation?

____.

Experiment 12: Image Formation from Spherical Mirrors

If you cut a very thin strip of mirror from along any diameter of a spherical mirror, the result is a close approximation to a thin cylindrical mirror. With this in mind, it is not surprising that images formed using spherical mirrors exhibit many of the same properties as those formed using cylindrical mirrors. In this experiment, you will investigate some of these properties.

EQUIPMENT NEEDED: Optics Bench, Light Source, Component Holder (3), 50 mm Focal Length Concave Mirror, Viewing Screen.



Equipment Setup

FOCAL LENGTH

Set up the equipment as shown above, with the concave side of the mirror facing the Light Source. The Viewing Screen should cover only half the hole in the Component Holder so that light from the filament reaches the mirror.

To verify the focal length of the mirror, position the mirror on the optical bench as far from the Crossed Arrow Target as possible. Vary the position of the Viewing Screen to find where the image of the target is focused.

1. What is your measured focal length for the concave spherical mirror?

   F.L. = ______________________________.

2. How might you determine the focal length more accurately?

   ____

   ____.

IMAGE LOCATION, MAGNIFICATION, AND INVERSION

In Experiment 7, you tested the validity of the Fundamental Lens Equation:

$$1/d_o + 1/d_i = 1/f,$$

for which the magnification of the image is given by the equation:

$$m = -d_i/d_o.$$

In this experiment you will test the validity of this same equation for image formation in a spherical mirror.

Vary the position between the concave mirror and the Crossed Arrow Target. At each position, place the Viewing Screen so the image of the target is in sharp focus. Use your data to fill in the following table. Perform the calculations shown in the table to determine if the Fundamental Lens Equation is also valid for real images formed from a spherical mirror. (If you are unfamiliar with the variables, review Experiment 7.)

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						

1. Are your results in complete agreement with the Fundamental Lens Equation? If not, to what do you attribute the discrepancies?

____

____.

VIRTUAL IMAGES

In the previous part of this experiment, you tested the Fundamental Lens Equation only for the concave mirror, and only for those cases in which a real image was focused between the object and the mirror. However, when an object is placed between a concave mirror and its focal point, a virtual image is formed. Virtual images can also be formed using a convex spherical mirror.

In the Appendix of this manual, read the section titled "Locating Virtual Images". Construct a table similar to that used above for real images and use the Image Locators to collect your data. Remember, for a virtual image, d_i is negative.

1. Are your results compatible with the Fundamental Lens Equation? If not, to what do you attribute the difference?

____

____.

Repeat the procedure with the convex side of the Spherical Mirror.

2. Does the Fundamental Lens Equation hold for images formed by convex spherical mirrors?

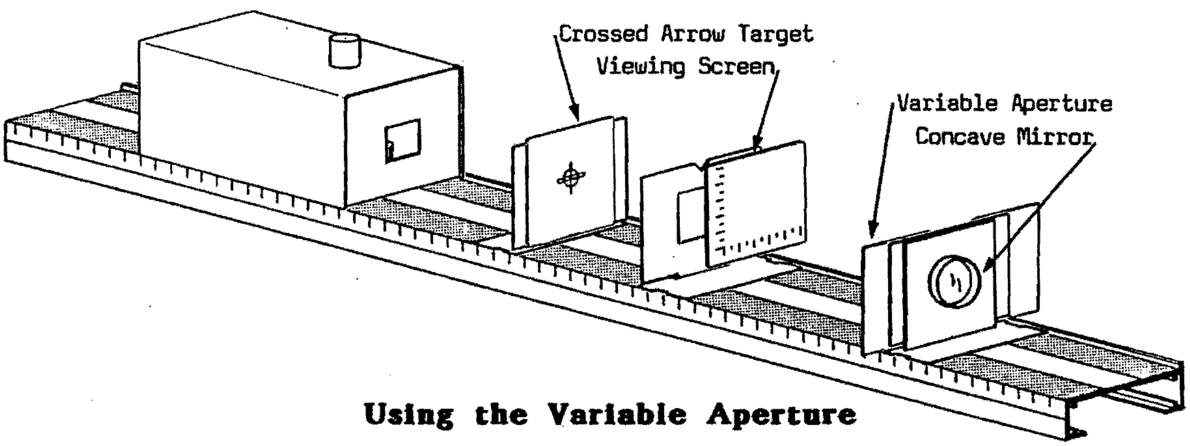
____.

CYLINDRICAL ABERATION

Adjust the position of the Light Source and Crossed Arrow Target so the image of the target on the screen is as large as possible.

1. Is the focus of the image sharpest at its center or at its edges? (This is a subtle effect which is easier to observe in a darkened room.)

____.



Using the Variable Aperture

Place the Variable Aperture on the Component Holder as shown above. The bottom of the V formed by the Aperture plates should be aligned with the notch in the top of the Component Holder.

2. Vary the size of the aperture. How does this affect the focus of the image?

____.

3. Explain your observations in terms of spherical aberation.

____

____.

4. What aperture size would give the best possible focus of the image? Why is this size aperture impractical?

____

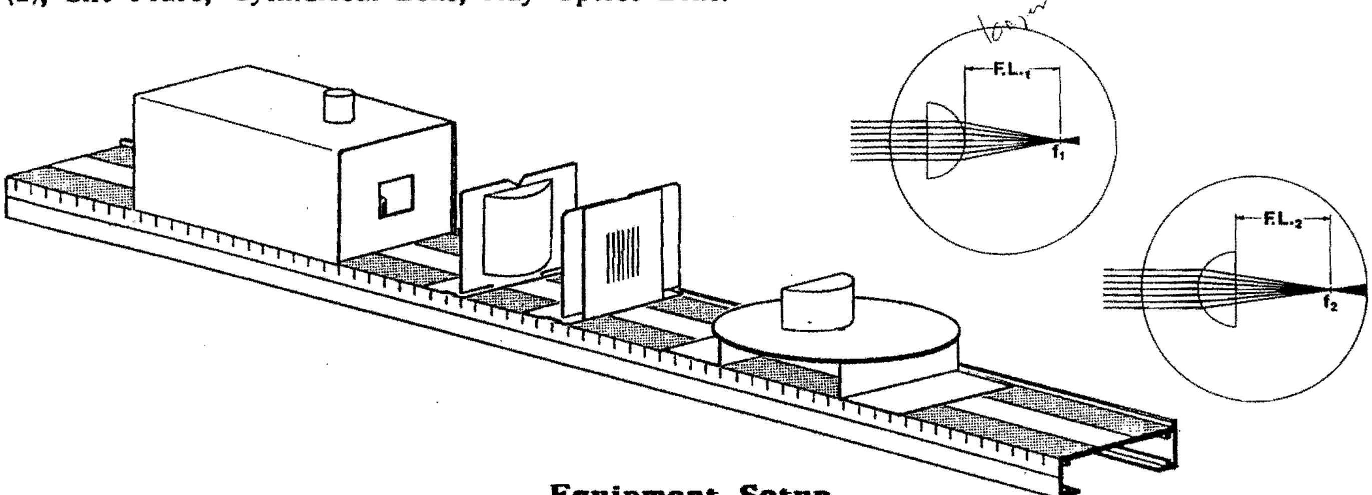
____.

Experiment 13: Image Formation with Cylindrical Lenses

You have investigated image formation through reflection. The principles at work in image formation through refraction are analogous. Similar ray tracing techniques can be used to determine the form and location of the image. The important differences are (1) the Law of Refraction replaces the Law of Reflection in determining the change in direction of the incident rays; and (2) the bending of the rays takes place at two surfaces, since the light passes into and then out of the lens.

In this experiment, you will use the Ray Table to study the properties of image formation with cylindrical lenses. The properties you will observe have important analogs in image formation with spherical lenses.

EQUIPMENT NEEDED: Optics Bench, Light Source, Ray Table and Base, Component Holder (2), Slit Plate, Cylindrical Lens, Ray Optics Lens.



Equipment Setup

Set up the equipment as shown above. Position the Cylindrical Lens on the Ray Table so the rays are all incident on the flat surface of the lens.

FOCAL POINT

Adjust the position of the Ray Optics Lens to obtain parallel rays on the Ray Table. Adjust the Cylindrical Lens so its flat surface is perpendicular to the incident rays and so the central ray passes through the lens undeflected.

1. Measure $F.L._1$ and $F.L._2$. (see the Equipment Setup illustration).

   $F.L._1$ = ______________________________.

   $F.L._2$ = ______________________________.

Remove the Ray Optics Lens. Arrange the Light Source and the Cylindrical Lens so that the filament of the Light Source is at f_1.

2. Describe the refracted rays.

____.

3. Place the filament at f_2 and describe the refracted rays.

____.

4. Why is one focal length shorter than the other? (Hint: consider the refraction of the light rays at both surfaces of the lens.)

____

____

____.

IMAGE LOCATION

Place the Light Source as far as possible from the Cylindrical Lens.

1. Where is the image formed?

____.

2. What happens to the location of the image as you move the Light Source closer?

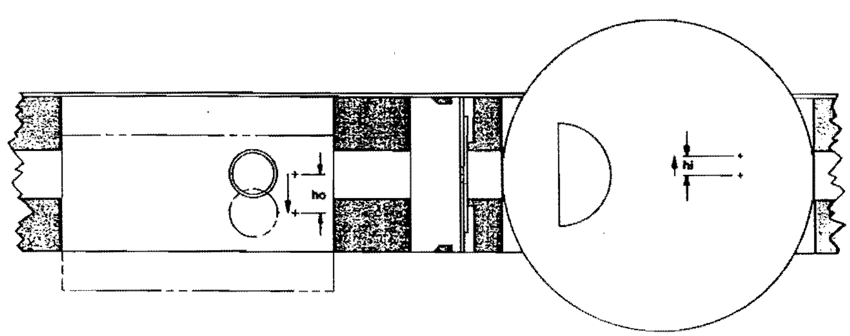
____.

3. Is an image still formed when the Light Source is closer than the focal length of the lens? If so, what kind?

____.

MAGNIFICATION AND INVERSION

In the plane of the Ray Table, the filament of the Light Source acts as a point source. To observe magnification and inversion, an extended source is needed. As shown below, two positions of the Light Source filament can be used to define an imaginary arrow.



Magnification and Inversion

Position the filament of the Light Source first at the tail of the arrow, then at the tip of the arrow. Locate the image for each position. The height of the image arrow, $\mathbf{h_i}$, divided by the height of the object arrow, $\mathbf{h_o}$, is the magnification of the image.

Measure the magnification for several different distances between the Light Source and the lens.

1. Qualitatively, how does the degree of magnification depend on the distance between the object and the lens?

   ____.

2. Is the image inverted? Is it inverted for all object locations?

   ____.

CYLINDRICAL ABERATION

Cylindrical aberation is the distortion of the image caused by imperfect focusing of the refracted rays. Place a blank sheet of paper over the Ray Table. Arrange the equipment so all the light rays are refracted from the Cylindrical Lens. Block all but two rays and mark their point of intersection. Do this for several pairs of rays.

1. Are all the rays focused at precisely the same point?

   ____.

2. How would you alter the shape of the lens to reduce the amount of cylindrical aberation?

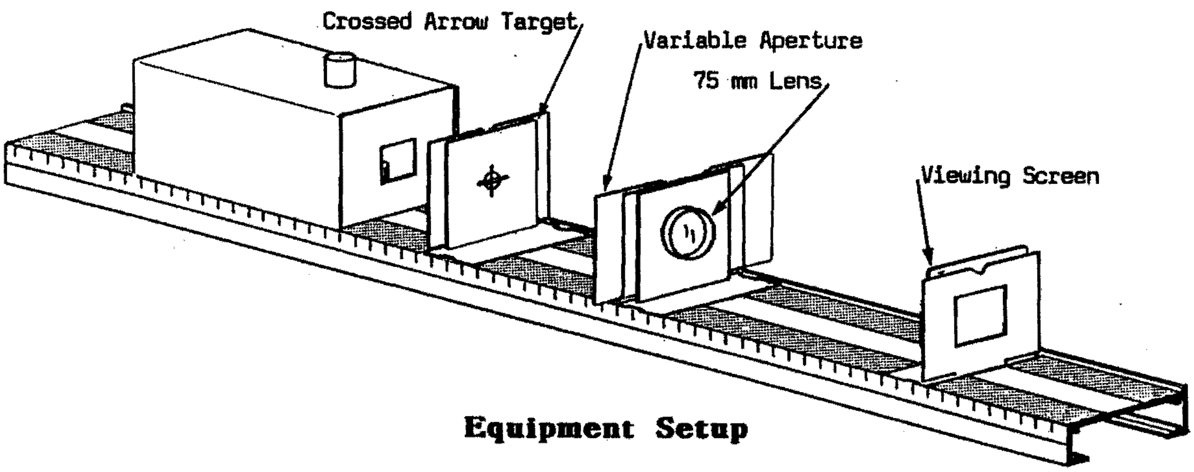
   ____.

Experiment 14: Spherical Lenses: Spherical and Chromatic Aberation, Aperture Size, and Depth of Field

No matter how perfectly a spherical lens is formed, there will always be some degree of image distortion. One source of distortion, spherical aberation, could be eliminated by changing the shape of the lens (from spherical to paraboloid). As you will see in this experiment, however, there are simpler ways of reducing, though not eliminating, spherical aberation.

Chromatic aberation arises because lens materials have slightly different indexes of refraction for different colors (wavelengths) of light. Because of this, incident white light is separated by a lens into its constituent colors, and different colored images are formed at slightly different locations. Chromatic aberation can be corrected only with the the use of compound lenses in which two or more lenses of different material and shape are combined.

EQUIPMENT NEEDED: Optics Bench, Light Source, 75 mm Focal Length Convex Lens, Variable Aperture, Crossed Arrow Target, Viewing Screen, Component Holders (3).



Equipment Setup

Setup the equipment as shown above. Begin with the Variable Aperture fully open. Vary the distance between the Lens and Viewing Screen until an image of the Crossed Arrow Target is focused on the screen.

SPHERICAL ABERATION

Slowly close the Variable Aperture. Be sure that the V formed by the two aperture plates remains centered on the notch at the top of the Component Holder. Observe the image of the Crossed Arrow Target on the screen.

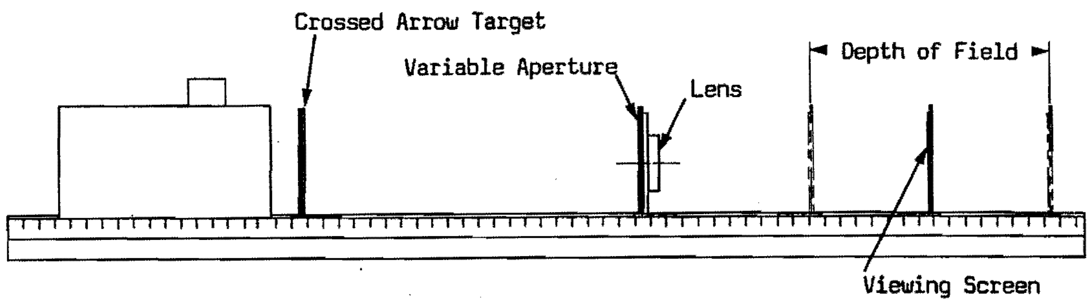
1. How is the focus of the image effected by the size of the aperture?

____.

2. What size aperture would give the best possible image focus? Why is this aperture size not practical?

____.

DEPTH OF FIELD



Depth of Field

In addition to spherical aberation, aperture size has an important effect on another variable of image focusing; depth of field. Depth of field is a measure of how much the distance between the lens and screen can be varied while still retaining a well focused image (see above).

To investigate this phenomenon, begin with the Variable Aperture fully open. Measure the depth of field. Now vary the size of the aperture, measuring the depth of field for each size.

1. How does depth of field depend on aperture size?

____.

2. Why is it not possible to have a depth of field that is infinitely long?

____.

With the aperture size very small (1-2 mm), remove the lens from the Component Holder.

3. Is an image of the Crossed Arrow Target still visible on the screen?

____.

4. How do variations in the size of the aperture affect the focus of the image?

____.

5. How does varying the distance between the Variable Aperture and the Viewing Screen affect the magnification of the image?

____.

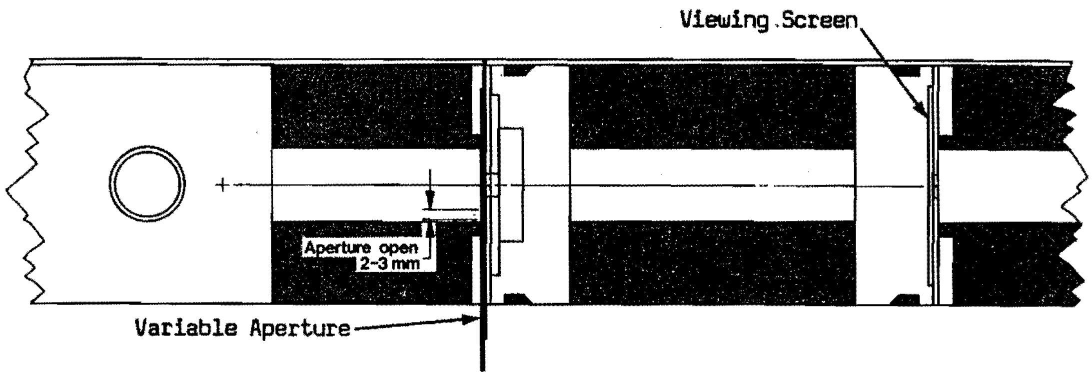
6. Why does a very small aperture allow formation of an image without using the lens? (Hint: consider the role played by the lens in focusing the diverging rays from a point object.)

____

____

____.

CHROMATIC ABERATION



Chromatic Aberation

Replace the lens and remove the Crossed Arrow Target from the Light Source. Using a small aperture size (2-3 mm), focus the filament of the Light Source onto the screen. Slide the aperture plates slowly to one side, away from the optical axis of the lens, as shown above. Do not change the size of the aperture. Notice the color separation in the image of the filament as the aperture gets sufficiently far from the optical axis of the lens.

1. Why is chromatic aberation more apparent when the aperture is far from the optical axis of the lens?

____

____.