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# Fresnel Biprism Interference Apparatus KSCIPFB

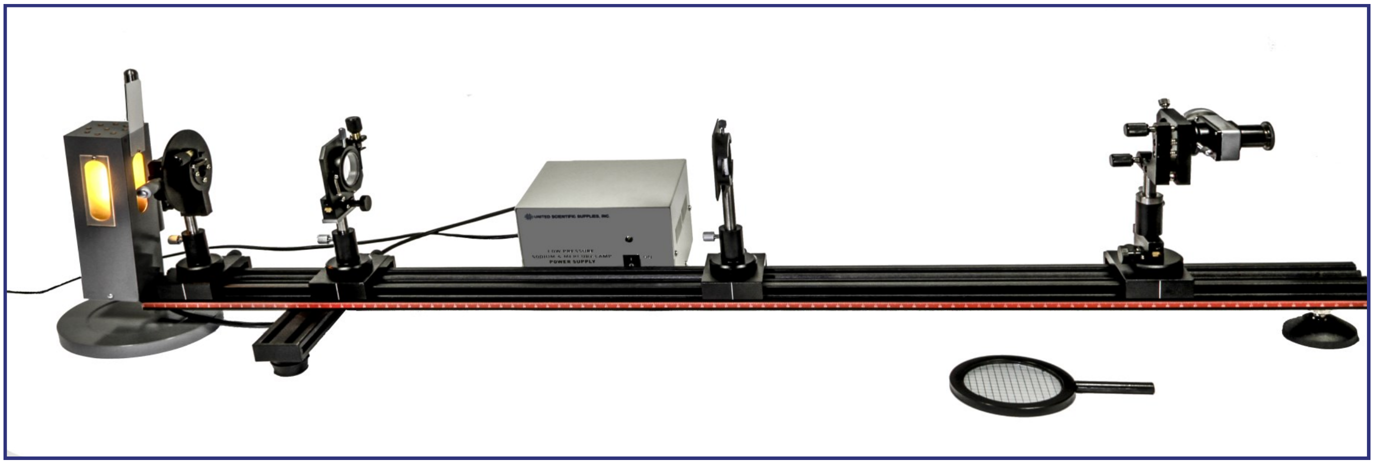


*Figure 1*

## INTRODUCTION

The Fresnel Biprism Interference Apparatus is a set of equipment that permits students to investigate an example of two-beam interference in an arrangement that is straightforward to set up, delivers bright interference images, and allows precise measurements to illustrate the elementary wave theory of interference.

## BACKGROUND

Interference phenomena occur when two or more wave trains are superposed. In order for these phenomena to be observed, the wave trains must fulfill certain conditions. The practical arrangement of interference experiments is governed by the measures taken to realize these conditions.

SUPERPOSITION OF WAVE TRAINS
The amplitude $\varphi_1(t)$ of a wave train of frequency ω at any point x may be written:

$$\varphi_1 = a \sin(\omega t - kx)$$

If a second wave train of the same frequency but different in phase by δ is superposed, its amplitude $\varphi_2$ at x is:

$$\varphi_2 = a \sin[\omega t - k(x + \delta)]$$

and it can be shown that the resulting combined amplitude φ is:

$$\varphi = 2a \cos(k\delta/2)\sin[\omega t - k(x + \delta/2)]$$

If $\delta = 0, \lambda, 2\lambda, \ldots$ $|\cos(k\delta/2)| = 1$ and the amplitude is 2a, a maximum. Here $\lambda = 2\pi/k$

If $\delta = \lambda/2, 3\lambda/2, 5\lambda/2, \ldots$ $\cos(k\delta/2) = 0$ and the amplitude is 0, a minimum.

The quantity λ represents the x-distance between corresponding points on two successive cycles of φ. In particular, it represents the distance between successive wave maxima or minima, and is therefore known as the wavelength.
Thus at the points where the resulting amplitude φ is 2a, the maxima of the two wave

trains coincide—the waves are “in phase”. Conversely, where the amplitude is zero, the maxima of the two wave trains are anti-coincident—”out of phase”.

COHERENT AND INCOHERENT DISTURBANCES

The above equations for $\varphi_1$ and $\varphi_2$ represent two infinite wave trains traveling in the positive x-direction with speed c. The resulting intensity distribution is an infinite series of equally-spaced “bright” and “dark” regions that do not move.
However, in practice, light sources do not emit infinite wave trains but finite “bursts” lasting in most cases about $10^{-8}$ seconds. Successive bursts have no phase relationship to one another. Thus the phase of the emitted light changes randomly about $10^{8}$ times per second.
*[Lasers are the prominent exception; they emit very much longer wave trains, but still change phase randomly between successive trains]*
This means that interference phenomena cannot be observed by using two identical but separate light sources. Although the interference phenomena do occur between the two light beams, the positions of the bright and dark points shift randomly $10^{8}$ times per second, obscuring the patterns. Such separate sources are said to be incoherent.
To produce two coherent light beams (i.e. beams always in a fixed phase relationship to one another), it is necessary to create both beams from a single light source. *[This includes lasers!]*
There are two practical methods for achieving this:

- “Division of wavefront” - splitting a spatially extended beam into two parts
- “Division of amplitude” - diverting a portion of a beam’s amplitude to a different path.

Fresnel’s method is division of wavefront.
*[Lasers are sometimes referred to as coherent light sources. Strictly, they are light sources of long coherence length. A non-laser light source emitting trains lasting less than $10^{-8}$ seconds produces trains no longer than 3 meters. In contrast, lasers produce trains of several kilometers. Separate lasers are still incoherent, but their very long coherence length and high brightness makes observing interference by either of the above techniques much easier]*

FRESNEL’S BIPRISM

In the biprism interference experiment attributed to French physicist and engineer Augustin-Jean Fresnel (1788-1827) the basic Young’s slits arrangement is improved by splitting the cylindrical wavefront radiating from a single narrow slit into two parts with a narrow-angle prism. The two beams overlap partially some distance behind the prism, and interference fringes are observable in the overlapping region (see *Figure 2*).

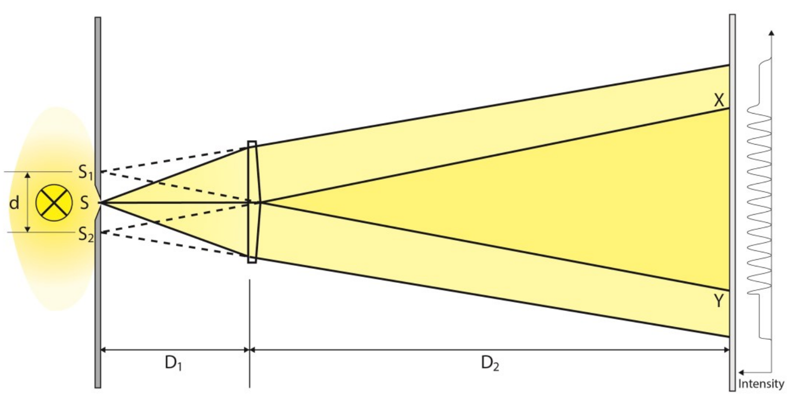



*Figure 2*

This arrangement is equivalent to a Young’s slits arrangement with the two slits replaced by virtual, coherent light sources ($S_1$ and $S_2$ in *Figure 2*) separated by a distance d which depends on the distance $D_1$ between the actual slit S and the prism.
An advantage of this arrangement compared with the Young’s slits setup is that the virtual sources eliminate the diffraction effects that disturb the Young’s slits fringes.
Applying Young’s formula for the separation x between neighboring fringes a distance

$D_2$ from the prism, we have:

$$x = \lambda(D_1 + D_2)/d$$

However, unlike the situation with Young's interference experiment, the distance d is not directly accessible for measurement. This difficulty is overcome by inserting a converging lens between the prism and the observing screen and using simple imaging theory.

The converging lens forms a real mage of the virtual sources on the screen. Without changing the distances $D_1$ and $D_2$, the lens is moved to bring the real images into focus. (*Figure 3*) The separation of the images, d', can now be measured directly, and the object and image distances, u and v, are noted. By the theory of conjugate foci, there will be a second lens position where the images are in focus, namely where the object and image distances are interchanged. Once more without changing the distances $D_1$ and $D_2$, the lens is moved to find this second focus and the new value of d' is measured.

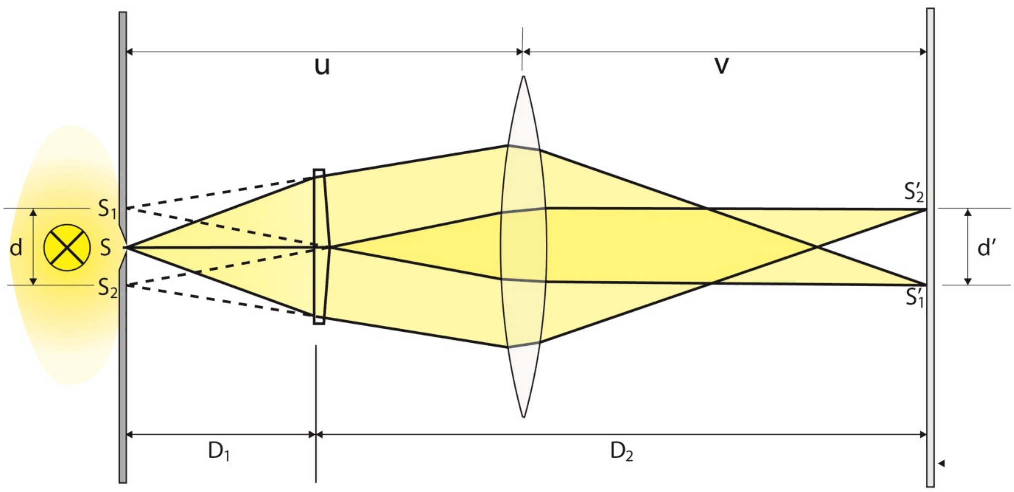



*Figure 3*

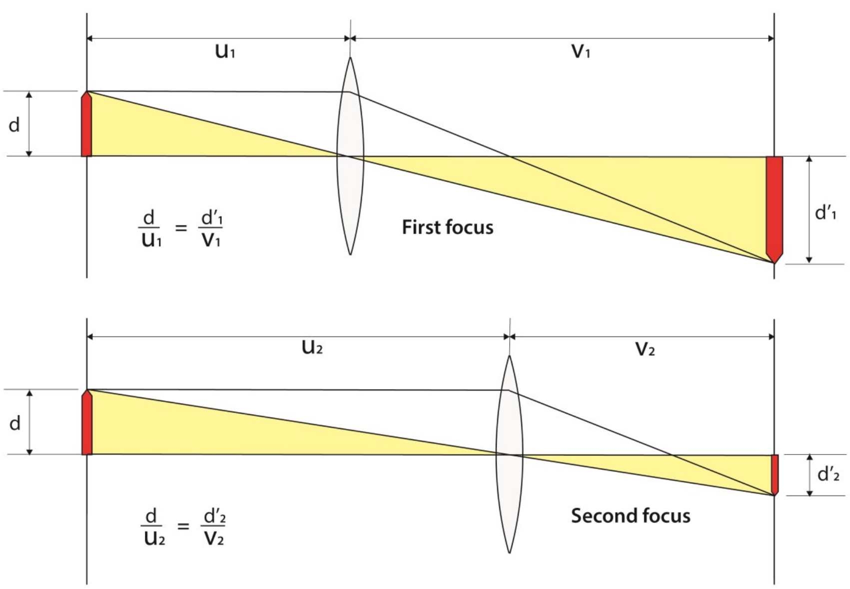



*Figure 4*

We have: $u_1 = v_2$ and $u_2 = v_1$ (1)

*Figure 4* illustrates the two image formations. Assuming that a ray directed towards the center of the lens is undeviated, we also have:

$$d/u_1 = d'_1/v_1, \quad d/u_2 = d'_2/v_2$$

Rearranging:

$$d'_1/d = v_1/u_1, \quad d'_2/d = v_2/u_2$$

So:

$$(d'_1/d)\cdot(d'_2/d) = (v_1/u_1)\cdot(v_2/u_2) = (v_1/v_2)\cdot(v_2/v_1) = 1 \text{ by using (1)}$$

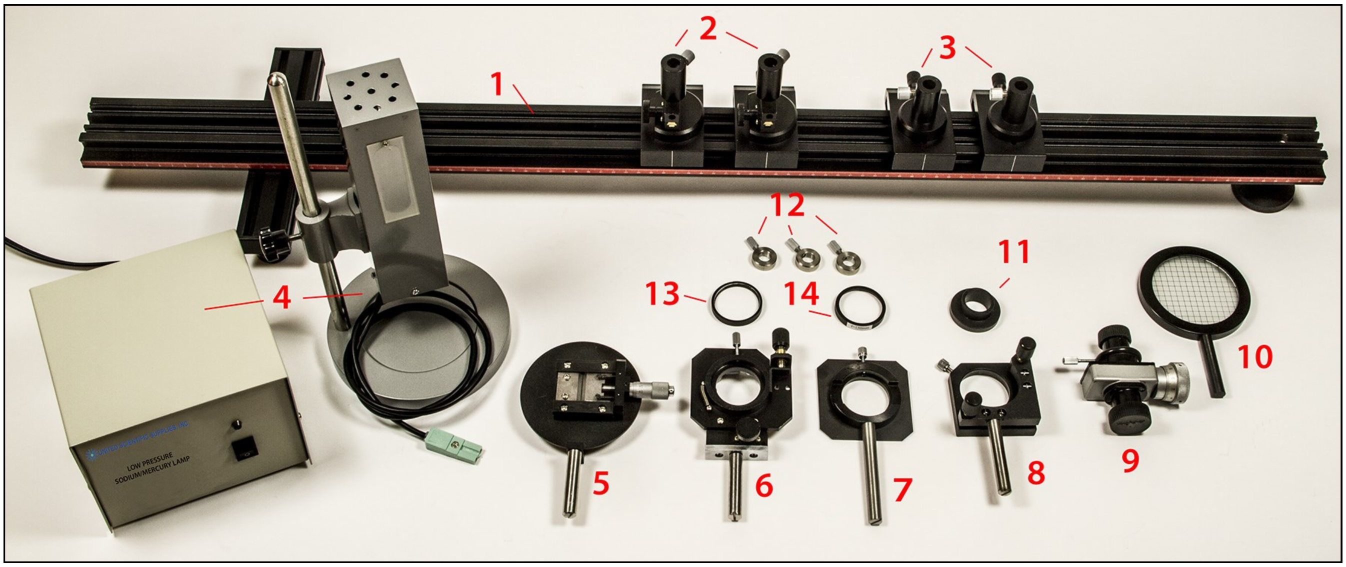
And we have:

$$d^2 = d'_1 d'_2 \text{ or } d = \sqrt{d'_1 d'_2}$$

The values of $d'_1$ and $d'_2$ are measured precisely using a micrometer eyepiece in place of the screen.

## THE EQUIPMENT

### DESCRIPTION OF THE PARTS




IDENTIFICATION OF COMPONENTS

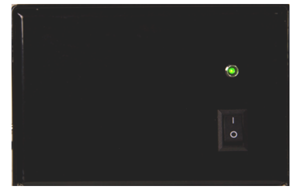
1. Optical bench, 1000 mm long
2. Riders with lateral adjustment (2)
3. Riders, plain (2)
4. Low pressure sodium lamp,20W/110V
5. Adjustable slit
6. Biprism carrier, adjustable
7. Lens carrier, plain
8. Eyepiece carrier, adjustable
9. Micrometer eyepiece, 0-8 x 0.01 mm
10. Ground glass screen
11. Eyepiece adapter ring
12. Height fixing collars (3)
13. Biprism
14. Converging lens, f = +150 mm

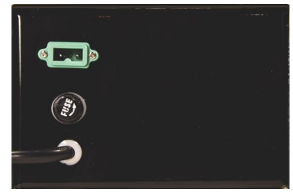
### Low Pressure Sodium Lamp and Power Supply

Monochromatic light for the interference experiment is provided by the low pressure sodium lamp. This unit consists of a 20W discharge lamp in a square metal housing with three exit ports covered by diffusing screens that can be swung away for maximum intensity, and a 110VAC power supply.

The lamp housing is attached to a stand rod and heavy base for vertical and angular adjustment. A connector on the lamp cord plugs into a matching socket on the rear panel of the power supply, and an on/off switch and power indicator light are located on the front panel.

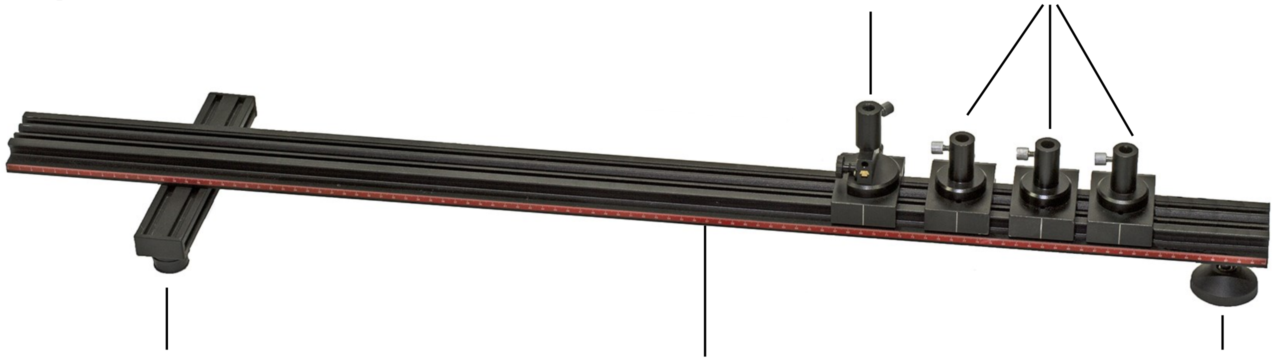
After switching on, the lamp takes about 20 minutes to warm up to full intensity with one port open, and a little less with all the ports closed. However, a usable intensity for initial setups should be achieved after only 10 minutes. Closing the diffusing screen reduces the intensity by about 45%.

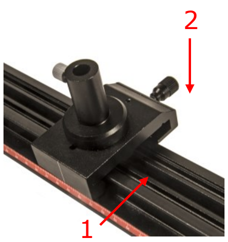



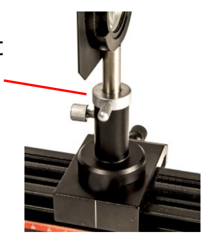

After switching the lamp off after use, allow the lamp to cool for several minutes before switching it on again. The discharge may not strike if the lamp is turned on while still hot.

## The Optical Bench and Riders

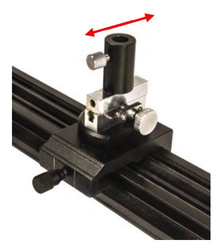



Attaching a rider

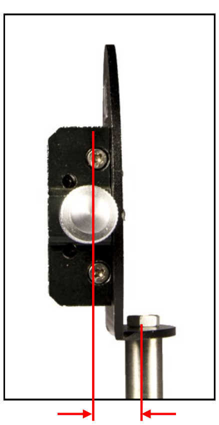



Aligning to
the optical axis

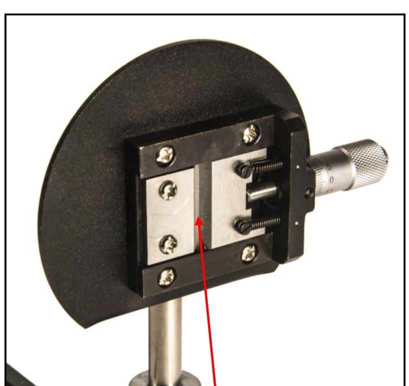


Transverse adjustment rider

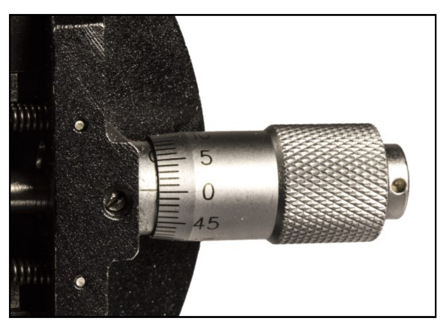
## The Adjustable Slit



15 mm offset between
plane of slit and center
of support rod.

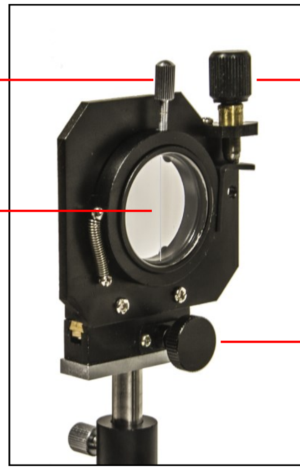


Fixed jaw edge
on centerline



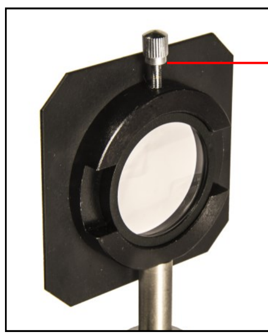

Moving jaw range is 0-2.50 mm

### The Biprism and Carrier




- There is a 15mm offset between the center of the biprism and the axis of the support rod
- The apex line of the biprism is not usually along a diameter of the holder due to manufacturing tolerances. The offset varies from unit to unit, and is usually less than 5mm, which is within the adjustment range of the transverse positioning mechanism.

### The Lens Holder and Lens

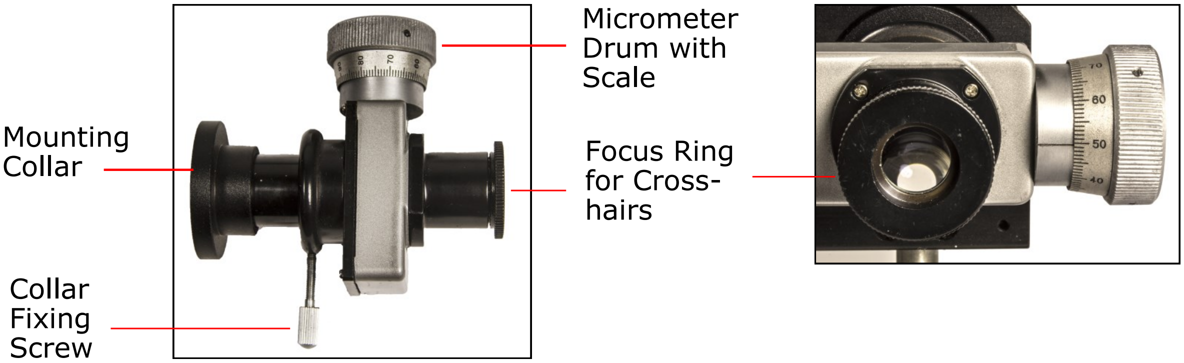



- The lens is mounted in a metal frame which fits into the recess in the holder and is fixed in place by a screw
- There is no offset between the plane of the lens and the axis of the support rod
- The nominal focal length of the lens is 150mm. It is advisable to determine the exact focal length of the lens separately for improved measurement accuracy.

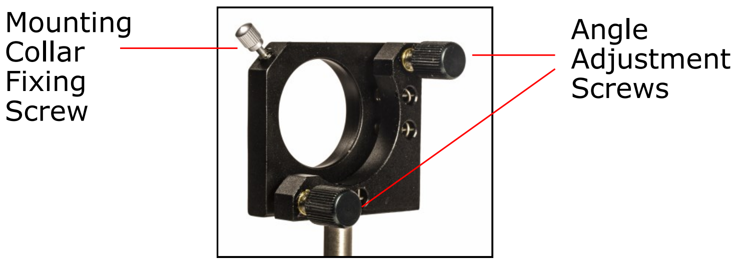
### The Ground Glass Screen

- The ground glass screen is used during the adjustment of the biprism and in the determination of the separation of the two virtual light sources.
- The screen has a diameter of 70mm and has a 5mm spacing square grid printed on it.
- There is no offset between the screen and the support rod axis.

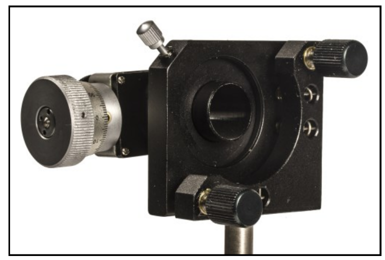
## The Micrometer Eyepiece




Micrometer Eyepiece




Eyepiece Holder



Mounted Eyepiece

- The micrometer eyepiece has a measurement range of 0—8.00mm with a resolution of 0.01mm (estimates to 0.005mm).
- When mounted, there is an offset of 55mm between the reticle that carries the internal scale and the axis of the support rod.
- The mounting collar fits into the circular hole in the holder and is fixed in place with a thumb-screw after adjusting the rotation angle so that the internal scale is horizontal.
- The mounted eyepiece can be adjusted left-right and up-down by two angle adjusting screws on the holder.

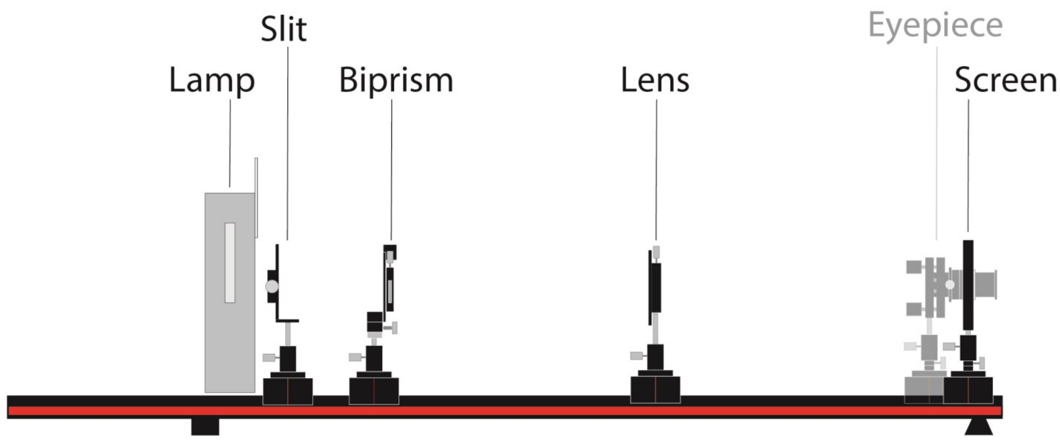
## SETTING UP THE EXPERIMENT AND MAKING MEASUREMENTS

The experiment is carried out in two parts:

Determining the separation of the virtual light sources;

Observing the interference fringes and deriving the light wavelength from measurements

Schematic of the arrangement of elements on the optical bench:




Arrange the items on the optical bench in the order shown in the schematic. For the first part of the experiment use the ground glass screen in place of the micrometer eyepiece. Make sure the heights of the centers of all the elements above the bench are the same. Use the height-fixing rings to avoid accidental slippage. Similarly, make sure the elements are squarely fitted into their holders and the holders are square to the axis of the optical bench.

Determining the separation of the virtual sources is accomplished by imaging the slit on the ground glass screen with the lens at each of the conjugate foci with the slit-screen separation unchanged.

The minimum slit-screen separation for real image formation is 60cm (4f). It is convenient for the separation to be a little greater than this minimum to provide two clearly distinct focus points. However, a much larger separation yields focused images that are greatly different in size, making it difficult to determine an exact focus for the smaller image. *Inspecting the images with a hand lupe for focus is helpful.* A convenient starting point is:

Initial positions (optical bench scale):

| | | |
|---|---|---|
| Slit: | 31.5 cm | Plain rider |
| Bi-prism: | 38.5 cm | Plain rider |
| Lens+150mm | 65.0 cm | Plain rider |
| Screen: | 92.5 cm | Traverse rider |

Adjusting the distance between the biprism and the slit will change the separation of the virtual slit sources. Smaller distances give smaller separations and wider fringes. 5-10 cm is a good choice.

Turn on the sodium lamp and allow it to warm up for about 10 minutes. Position it as close to the slit as possible and flip the diffusing screen up out of the way to give the slit as much light as possible.

**Determine the separation d of the two virtual light sources**:

Using the screen, focus the images of the slit twice by *moving the lens only*. Record the positions of the lens at the foci. (slit open to about 50 divisions)

Adjust the lateral position and angle of the bi-prism to make the apex edge exactly parallel to the slit and centered on it. Two equally bright, parallel slit images should appear on the screen. *It is worth spending some time to achieve this as precisely as possible, since an accurate adjustment greatly improves the visibility of the fringes.*

Replace the screen by the micrometer eyepiece. Adjust the ocular until the scale and cursor appear sharp. Adjust the eyepiece position on the bench until the slits are sharply in focus. Reduce the slit width to 3-5 divisions, then measure and record the separation of the centers of the two slit images.

Replace the screen and reposition it to its original location. Open the slit to about 50 divisions again. Move the lens to find the conjugate focus, record the lens position, then repeat the measurement of the separation of the centers of the slit images as before.

If d is the virtual slit separation and $d_1$ & $d_2$ are the measured image separations, we have

$d/u = d_1/v$ and $d/v = d_2/u$ since the foci are conjugate. (use the measured lens positions to check that $u_1 = v_2$ and $v_1 = u_2$. Remember to take account of the offsets between the elements and the axes of their holders. If not, go back and re-check the foci.

So $d^2/uv = d_1 d_2/vu$, and $d = \sqrt{(d_1 d_2)}$.

**Viewing/measuring the fringes**:

View the fringes by setting the slit width to 3-5 divisions then moving the lens along the bench while observing the pattern through the micrometer eyepiece. Choose a position where a large number of fringes are clearly visible and use the micrometer eyepiece to measure several fringe separations and confirm their even spacing.

Also confirm that the fringes are restricted to the area where light from the two virtual sources overlaps.

To measure the wavelength of the sodium light (589.3 nm) remove the lens and darken the room. Set the slit width to 3-5 divisions.

Adjust the position of the micrometer eyepiece until about 20 fringes can be seen. Record its position.

Fine-tune the image by adjusting the lateral position and angle of the bi-prism. Track the center of the image in the eyepiece using the lateral adjustment on its rider.

Measure the fringe separation x with the eyepiece. (measuring between dark fringes is easier) Then

$\lambda = xd/D$, where d is the previously measured virtual slit separation and D is the distance between the slit and the eyepiece positions. Remember to take account of the offsets between the elements and the axes of their holders.

## EXAMPLES:

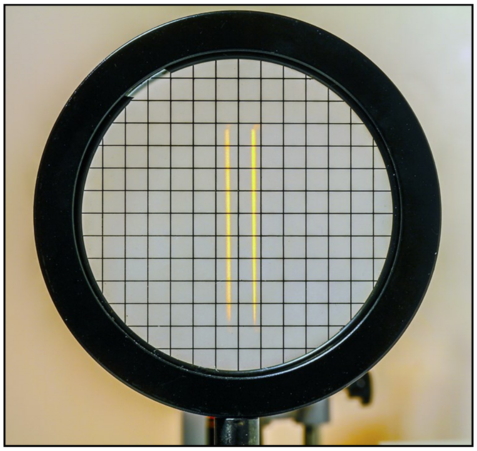


Image of a well-adjusted slit/ biprism combination

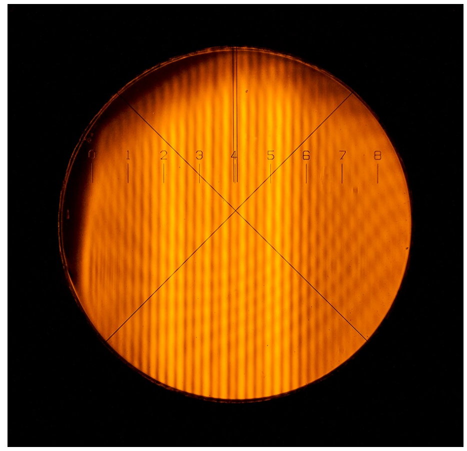


Image of Fresnel interference fringes (with lens)

Sample measurements:

| | | | | |
|---|---|---|---|---|
| Slit at: | 31.5 | Offset -1.5 | Element position: | 30.0 cm |
| Biprism at: | 38.5 | +1.5 | | 40.0 cm |
| Lens at: 1: | 55.1 | 0 | | 55.1 cm |
| 2: | 67.6 | 0 | | 67.6 cm |
| Screen at: | 92.5 | 0 | | 92.5 cm |

$u_1$ = 25.1 cm $v_1$ = 37.4 cm
$u_2$ = 37.6 cm $v_2$ = 24.9 cm

Measurement of d:

$d_1$ = (4.33 - 2.58)mm = 1.75 mm
$d_2$ = (4.245 - 3.48)mm = 0.765 mm
**d = 1.157 mm**

Measurement of fringes:

Eyepiece at: 89.5 Offset= +5.5 Element position: 95.0 cm
**D =** (95.0 - 30.0) cm = **650 mm**

Fringe count starts at: 0.355 mm
Ends at: 6.855 mm
Number of fringes (dark-to-dark):20

**x = 0.325 mm**

$\lambda$ = **xd/D = 578.5 nm.** Error = -10.8 nm = 1.8%

Primary source of error: correct estimation of focus points in measuring d.