4.2 Determining the nodal locations & measuring the focal length of a lens-group

Components required: white light source, millimetre ruler, biprism holder, lens holder, lens-group holder, eyepiece of measurement microscope, eyepiece holder, flat mirror, white screen, and lenses f'=150, 190, and 300 mm.

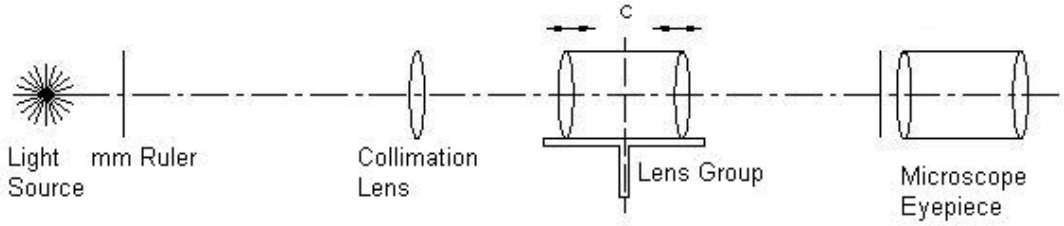


Figure 4.2-1 Schematic of experiment setup

Note: to adjust the distance between the two lenses of the lens group, release the front lens from the connecting screw of the two lenses, set the desired distance for the two lenses, and reconnect the front lens to the connecting screw.

Experimental Procedure:

1) Referring to Figure 4.2-1, adjust the distance between millimetre ruler and collimating lens *Lo* to obtain a collimated beam from *Lo* with the assistance of a flat mirror (self-alignment method);
2) Build a lens group using two concave lenses (e.g. f190 mm and f300 mm) on the lens group holder. Place the lens group and the eyepiece of measurement microscope on the optical rail, align them at the same height as other optical parts, move eyepiece back and forth until a clear image of millimetre ruler is observed; (may use a white screen to replace the eyepiece to observe the image.)
3) Move the lens group back and forth along the rack of the lens group holder (note: the carrier of the lens group holder is fixed), while moving the eyepiece to follow the clear image. After each movement of the lens group, rotate it around its vertical axis (i.e. the post of the lens group holder), until the ruler image in the eyepiece doesn't have transversal displacement as the lens group rotating. At this moment, the image space node of the lens group is located on the rotation axis of the lens group holder;
4) Replace eyepiece with a white screen (image screen), observe the ruler image, write down the locations of the screen and lens group holder on the optical rail as *a* and *b*, respectively. Also write down the deviation amount *d* of the central location of the lens group (marked on the lens group frame) from the rotation axis of the holder;
5) Reverse lens-group holder by 180°, repeat steps 3 and 4, obtain another set data of *a'*, *b'* and *d'*;
6) Data processing: the distances of image space node and object space node from the lens group centre are *d* and *d'*, respectively, and the focal lengths of the lens group in image space and object space are $f = a - b$ and $f' = a' - b'$, respectively;

7) Make a 1:1 drawing to show the measured lens group and relative positions of the cardinal points of the lens group.

4.3 Determining the magnifications of a microscope and a telescope

Components required: white light source, sodium lamp, plate holder, 1/10 mm reticle, millimetre ruler, biprism holder, lens holder(3), 45° glass holder, microscope eyepiece, stand ruler, adapter piece(extension to both ends), and lenses f'=45 and 225 mm.

4.3.1 Magnification of a microscope

As shown in Figure 4.3-1**,** the optical system of a microscope employs an objective with a short focal length and a magnifying eyepiece. The magnification is achieved in two stages as shown in Figure 4.3-1. The microscope objective forms an enlarged image of the object in a position that is suitable for viewing through the eyepiece; the magnification through the objective is given by

$$y_2/y_1 = \Delta / f_o' \tag{4.3-1}$$

Generally speaking, the focal length of the eyepiece f_e' is much less than the distance of the image from the eyepiece D, (for normal sight, D is approximate 250 mm), so

$$y_3/y_2 \approx D/ f_e' \tag{4.3-2}$$

Then we get the total magnification:

$$M = \frac{y_3}{y_1} = \frac{y_3}{y_2}\frac{y_2}{y_1} = \frac{D\Delta}{f_o' f_e'} \tag{4.3-3}$$

Where Δ is the distance between the focus of objective and the focus of eyepiece, f_o' is the focal length of objective, and f_e' is that of eyepiece.

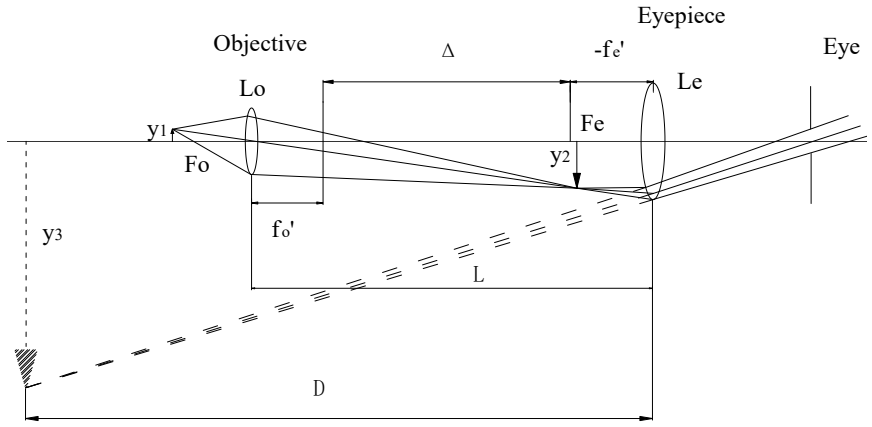


Figure 4.3-1 Schematic of microscope imaging

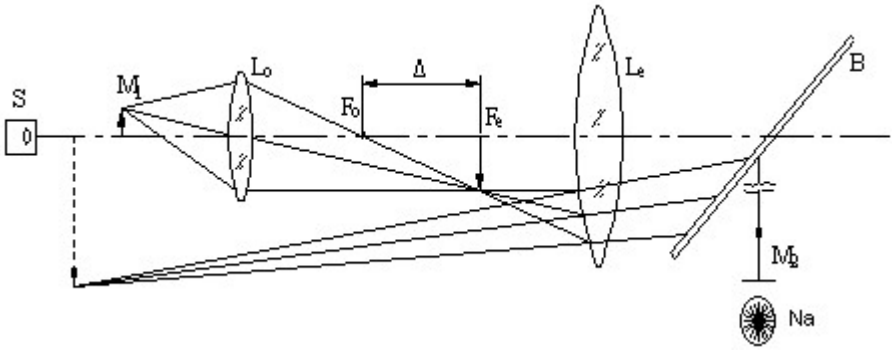
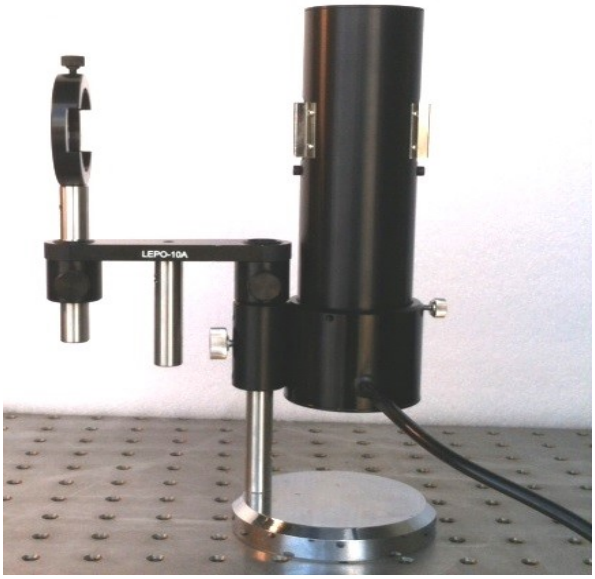


Figure 4.3-2 Schematic of experiment setup

S: white light source, M_1: 1/10 mm reticle mounted on biprism holder, L_0: objective, L_e: eyepiece, Na: sodium lamp, M_2: millimetre ruler, B: beam splitter (i.e. 45° glass).

Experimental Procedure:

1) Refer to Figures 4.3-2, align all components at the same height along the rail;
2) Set the interval between *L*o and *L*e as $D = 240$ mm;
3) Move reticle plate M_1 back and forth, till a clear M_1 virtual image is observed behind *Le*;
4) Mount the beam splitter *B* (45° glass) onto the post of the eyepiece L_e;
5) Mount the millimetre ruler M_2 on a lens holder. Assemble the millimetre ruler with the Sodium lamp according to the picture below. Place the assembly beside *B* (vertical to main optical axis) at approximately 250 mm away from *B*; illuminate the ruler using the sodium lamp;



6) View behind *B* by one eye, finely rotate *B*'s angle to overlap the microscope virtual image from M_1 and the M_2 image from the glass reflection; *Note, properly adjust the brightness of the two images to achieve close viewing effect by changing the distance of one illumination source or attenuate the brightness of one light source*.

7) Finely adjust M_1 to eliminate viewing difference between the two images;

8) Count the scale amount *a* in M_1 image included in the range of 30 mm of image M_2;

9) Calculate the measured magnification of the assembled microscope and compare it with the theoretical magnification:

Measured Magnification: $M = \dfrac{30 \times 10}{a}$

Theoretical Magnification: $M' = \dfrac{250 \times \Delta}{f_o' f_e'}$, where, $\Delta = D - (f_o' + f_e')$.

4.3.2 Magnification of a telescope

As seen in Figure 4.3-3, the magnifying power of a telescope used for observing an object at infinity is defined as the angular magnification at the pupil because the angles are very small:

$$M = \frac{\tan \omega'}{\tan \omega} = \frac{\omega'}{\omega} = \frac{f_o'}{f_e'} \tag{4.3-4}$$

where f_o' and f_e' are the focal lengths of the objective and eyepiece lenses, respectively, *w*' and *w* ar e the object and image angles at the eyepiece and objective lenses, respectively.

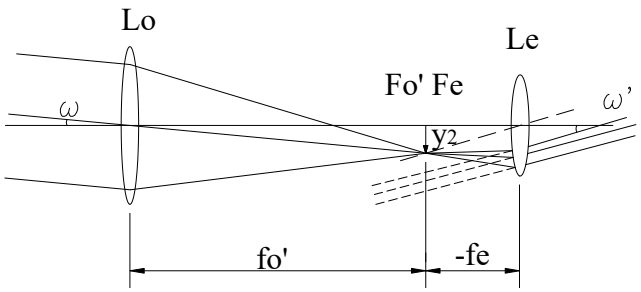


Figure 4.3-3 Schematic of telescope imaging at infinity

As shown in Figure 4.3-4, when observing an object at quasi-infinity, the power of magnification is:

$$M = \frac{\tan\omega'}{\tan\omega} = \frac{y_2 / s_2}{y_1 /(s_1 + s_1^{'} + s_2)} \tag{4.3-5}$$

Since $y_2/y_1=s_1'/s_1$, therefore,

$$M = s_1^{'}(s_1 + s_1^{'} + s_2)/s_1 s_2 \tag{4.3-6}$$

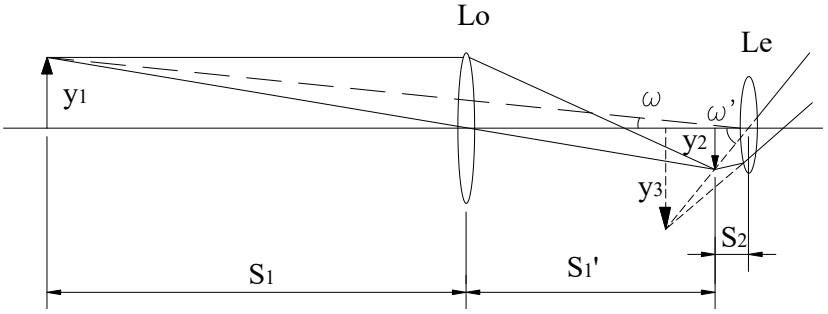


Figure 4.3-4 Schematic of telescope imaging at quasi-infinity.

Experimental Procedure:

1) Refer to Figure 4.3-4, align L_o and L_e at the same height on the rail, spaced by f_o+f_e approximately, and place the stand ruler in front of L_o at a distance of about 3 meters;
2) Move objective lens *L*o back and forth, behind *L*e while observing the image of the ruler with one eye until a clear image is observed;
3) Use another eye to observe the scale marks on the ruler, count how many scale marks (amount *M'*) on the ruler image are contained in one mark of the magnified image of the telescope; *M'* is the measured magnification of the telescope;
4) Calculate magnification *M* using Eq. (4.3-4), compare it with *M*'.

4.4 Young's double-slit interference

Components required: Sodium lamp with pinhole aperture (1 mm), adjustable slit, double-slit, eyepiece of DMM, eyepiece holder, lens holder (2), biprism holder, lenses f'=45 and 150 mm.

Principle

To get an interference pattern, the two beams exited from the slits must have the same frequency with a fixed phase relation. Generally speaking, most light sources cannot satisfy this condition. In 1801, Thomas Young allowed a single, narrow beam of light to fall on two narrow, closely spaced slits. He placed a viewing screen opposite to the slits. When the light from the two slits struck the screen, a regular pattern with alternative dark and bright rings appeared. When first performed, Young's experiment offered an important evidence for the wave nature of light. The schematic of Young's double-slit interference is shown in Figure 4.4-1.

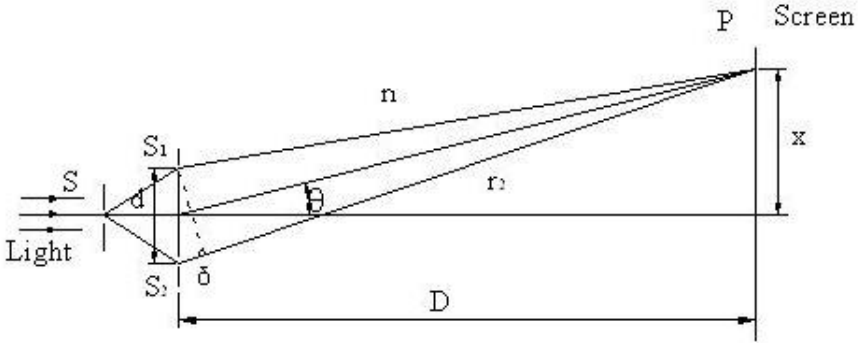


Figure 4.4-1 Schematic of Young's double-slit experiment

In this way, the light emitted from S_1 and S_2 has a definite phase relation because the secondary wave sources from the same wave surface S are always coherent. The light path difference (d is the distance between the two slits of the double-slit plate) is:

$$\delta = r_2 - r_1 \approx d\sin\theta \approx d\tan\theta = d\frac{x}{D} \tag{4.4-1}$$

where D is the distance between the viewing screen and the slits, x is the vertical distance between the viewing location and the center of the double slits, and θ is a half of the viewing angle between the lines from the viewing point on the screen to the two slits. If the path difference between a particular point on the screen to the two slits equals to a half of the wavelength (or multiples

thereof) of the light, then complete destructive interference will occur at that point, and thus a dark spot will be observed.

$$\delta = d\frac{x}{D} = \pm(2k+1)\frac{\lambda}{2} \quad \text{(Dark interference fringes)} \quad (4.4\text{-}2)$$

Conversely, if the path difference equals to an integer multiple of the wavelength of the light, then complete constructive interference will occur, and a bright spot will appear on the screen.

$$\delta = d\frac{x}{D} = \pm k\lambda \quad \text{(Bright interference fringes)} \quad (4.4\text{-}3)$$

So the distance between two adjacent dark fringes (or bright fringes) is:

$$\Delta x = \frac{D}{d}\lambda \quad (4.4\text{-}4)$$

In this formula, as Δx and D can be measured, if we know either d or λ, we can calculate the other. If a laser rather than a Sodium lamp is used as the source, the experiment will be easier to conduct and the interference fringes will be observed more obviously.

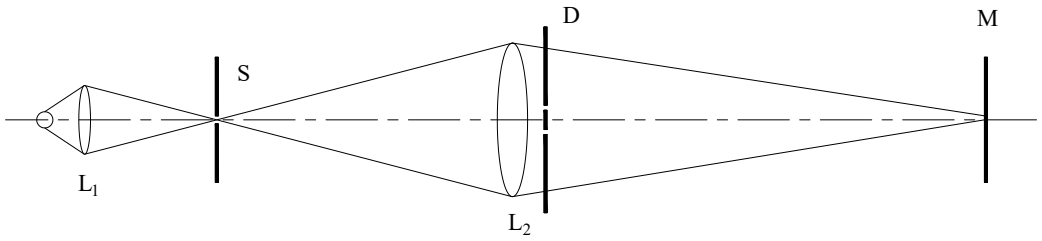


Figure 4.4-2 Schematic of experiment setup

Experimental Procedure:

1) Refer to Figure 4.4-2, a monochromatic light source (e.g. Sodium lamp) is focused onto single slit S through lens L_1;
2) Image S onto the reticle plate of eyepiece M using lens L_2, then place the double-slit plate immediately behind L_2. The key to the success of this experiment is to align the double-slit and the single slit to be parallel to each other;
3) Observe double-slit interference pattern through the eyepiece of the direct measurement microscope, equal-interval bright/dark fringe pairs will be observed;
4) Measure interval e between two adjacent fringes using direct measurement microscope, also measure distance L between the double-slit plate and the microscope;
5) Use interval t of the double slits and expression of $e=L\lambda/t$ to derive wavelength λ of the illumination light.