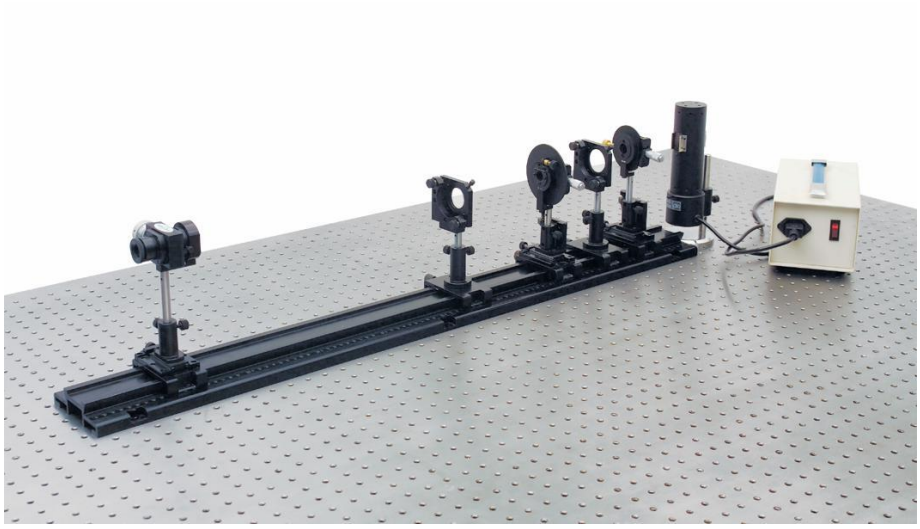
LEOK-6 Optics Experiment Kit

Instruction Manual



Lambda Scientific Systems, Inc

14055 SW 142nd Avenue, Suite 22, Miami, FL 33186, USA
Phone: (305) 252-3838; Fax: (305) 517-3739
E-mail: sales@lambdasys.com; Web: www.lambdasys.com

 V.I

COMPANY PROFILE

Lambda Scientific Systems, Inc. specializes in developing and marketing scientific instruments and systems designed and manufactured specifically for experimental education in physics at colleges and universities. Our mission is to become a premier supplier of high-quality, robust, easy-to-use, and affordable scientific instruments and systems to college educators and students for their teaching and learning of both fundamental and modern experiments in physics. Our products focus on comprehensive physics education kits, as well as light sources and opto-mechanic components.

Our physics education kits cover a wide range of experiments in general physics, especially in geometrical optics, physical optics, and fiber optics. Experiments include lens imaging, interferometry, diffraction, holography, polarization, laser physics, quantum optics, and Fourier optics through a series of the most representative apparatus such as Newton's ring apparatus, Young's modulus apparatus, Michelson interferometer, Fabry-Perot interferometer, Twyman-Green interferometer, Fourier spectrometer, and laser.

Our fiber optics education kits keep a pace with the advent of fiber optical communication technology by designing experimental systems to teach fundamental optical fiber concepts such as fiber-to-fiber coupling, fiber-to-source coupling, fiber numerical aperture, fiber mode, fiber transmission loss, and fiber sensing. These kits also give students an opportunity to be familiar with modern fiber optic components or apparatus such as Mach-Zehnder interferometer, variable optical attenuator, fiber isolator, fiber splitter, fiber switch, wavelength-division multiplexer, fiber amplifier, and transmitter.

Our light sources include Xenon lamp, Mercury lamp, Sodium lamp, Bromine Tungsten lamp and various lasers.

We also provide a variety of opto-mechanical components such as optical mounts, optical breadboards and translation stages. Our products have been sold worldwide. Lambda Scientific Systems, Inc is committed to providing high quality, cost effective products and on-time delivery.

CONTENTS

1. Introduction

The LEOK Optics Experiment Kits are developed for general optics education at universities and colleges. LEOK-6 is an extension of LEOK-1 to include more experiments on the topic of optical polarization. It can be used to construct more than one dozen of experiments, covering the basic experiments in geometrical optics, physical optics, and information optics. LEOK-6 can be further upgraded to include extra experiments by adding the corresponding parts from LEOK-3. LEOK-6 offers an affordable solution to cover a wide range of optical properties and principles. All experiments are performed along a rail and hence the system is suitable under normal lab environment.

2. List of Parts

There are two models for this kit, using a 1-m rail (LEOK-6A) and a 1.5-m rail (LEOK-6B) as the platform with other parts (specifications) listed in the table below.

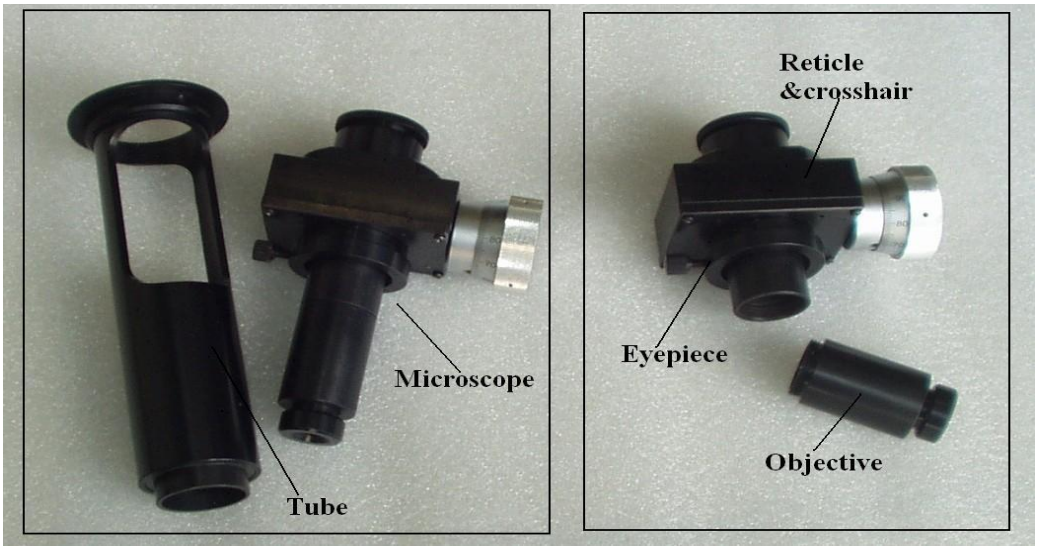
No.	Description	Specs/Part#	Qty
1	Optical Rail	1 m (LEOK-6A), 1.5 m (LEOK-6B)	1
2	Adjustable Carrier	two-axis translation (DGL-1-03A)	2
3	Adjustable Carrier	one-axis translation (DGL-1-02A)	1
4	General Carrier	DGL-1-01A	2 (LEOK-6A), 3 (LEOK-6B)
5	Polaroid Holder	SZ-51	3
6	Kinematic Lens Holder	SZ-07	1
7	Lens Holder	SZ-08	2 (LEOK-6A), 3 (LEOK-6B)
8	Adapter Piece	SZ-09	1
9	Adapter Piece	SZ-09A (extension to both ends)	1
10	Plate Holder A	SZ-12	1
11	White Screen	SZ-13	1
12	Object Screen	SZ-14	1
13	Single-Side Adjustable Slit	SZ-27	1
14	Rotary Adjustable Slit	SZ-40	1
15	Lens Group Holder	SZ-28	1
16	Stand Ruler with Tripod	SZ-33	1
17	Spatial Filter Set	directional, low pass, high pass, band pass, and aperture	1 (LEOK-6B only)
18	Optical Aperture Stop	transmit on-axis and off-axis light beams	1
19	Fresnel Bi-Mirror	SZ-31	1
20	DMM Holder	SZ-36	1
21	Biprism Holder	SZ-41 (rotary, also for Double Slit, Mini Ruler, etc)	1
22	Laser Tube Holder	SZ-42	2

23	45 degree Glass Holder	SZ-45 (for microscope experiment)	1
24	Optical Goniometer	SZ-47, 360°, w/ rotary arm	1
25	Iceland Crystal w/ Rotary Holder	SZ-48 (or SZ-06A)	1
26	Mounted Lenses	f'= 45, 70, 105, 150, 190, 225, 300, -100 mm	each 1
27	Mounted Beam Expander	f'= 4.5 mm	1
28	Mounted Optical Filter	Red and Blue	each 1
29	Mounted Double Slit	d=1.15 or 1.35 mm	1
30	Mounted Biprism	Φ 36 mm	1
31	Mounted Plane Mirror	Φ 36 mm	1
32	Mounted Polarizer	Φ 20 mm	2
33	Mounted 1/4 Waveplate	at 632.8 nm, quartz	1
34	Mounted Reticle	1/10 mm, film	1
35	Mounted Millimeter Ruler	l =30 mm, film	1
36	Eyepiece	f'=34 mm, doublet	1
37	Black Glass	used as Lloyd's Mirror	1
38	Direct Measurement Microscope (DMM)	field 8 mm (dismount objective to get eyepiece)	1
39	Liquid Tube	l =250 mm (+4 mm for 2 retaining rings)	1
40	Low-Pressure Sodium Lamp	LLE-2, 20 W with power supply	1
41	Support of Lamp Housing	A carrier with a post	1
42	Bromine Tungsten Lamp	LLC-3 / 12 V; 30 W, variable	1
43	He-Ne Laser	1.5 mW with power supply	1
44	Ground Glass Screen	SZ-43	1 (LEOK-6B only)
45	Diffraction Pinhole	Φ 0.3 mm	1
46	Grating	20l /mm	1 (LEOK-6B only)
47	Character with Grid		1 (LEOK-6B only)
48	Theta Modulation Plate		1 (LEOK-6B only)
49	2-D Cross Grating		1 (LEOK-6B only)

*Note: parts are subject to change without notice.

*Configuration of the direct measurement microscope:

The objective lens images an object located on the bottom plane of the tube onto the reticle plate in the eyepiece with a magnification ratio of 1:1. For this kit, the eyepiece is usually used as a standalone device. Refer to the photo below to dismount the objective and mount the eyepiece onto the DMM holder.



3. List of Experimental Examples

Using this experiment kit, the following experimental examples can be conducted:

1. Lens imaging:
    a. Measuring the focal length of a thin convex lens using lens imaging equation
    b. Measuring the focal length of a thin convex lens using auto-collimation
    c. Measuring the focal length of a thin convex lens using the Bessel method
    d. Measuring the focal length of a concave lens
    e. Demonstrating spherical and chromatic aberrations of a convex lens
2. Determining the nodal locations & measuring the focal length of a lens-group
3. Determining the magnifications of a microscope and a telescope
4. Young's double-slit interference
5. Interference of Fresnel's biprism
6. Interference of double mirrors
7. Interference of Lloyd's mirror
8. Fraunhofer diffraction of a single slit
9. Fraunhofer diffraction of a single circular aperture
10. Examining light polarization:
    a. generating polarized light by reflection and the Brewster angle
    b. generating polarized light by dichromatic material
    c. birefractive characteristic of crystal
    d. elliptically polarized light
    e. circularly polarized light
11. Effect of optical activity (polarization rotation)
12. Abbe imaging principle and optical spatial filtering (LEOI-6B only)
13. Pseudo-color encoding, theta modulation and color composition (LEOI-6B only)

4. Details of Experimental Examples

4.1 Lens imaging

Components required: white light source, object screen, flat mirror, image screen, optical stop aperture (can be used as on-axis or off-axis hole), optical filters (blue and red), lens holder (2), lenses f'= 105, 150, and -100 mm, respectively.

4.1.1 Measuring the focal length of a thin convex lens using the lens imaging equation

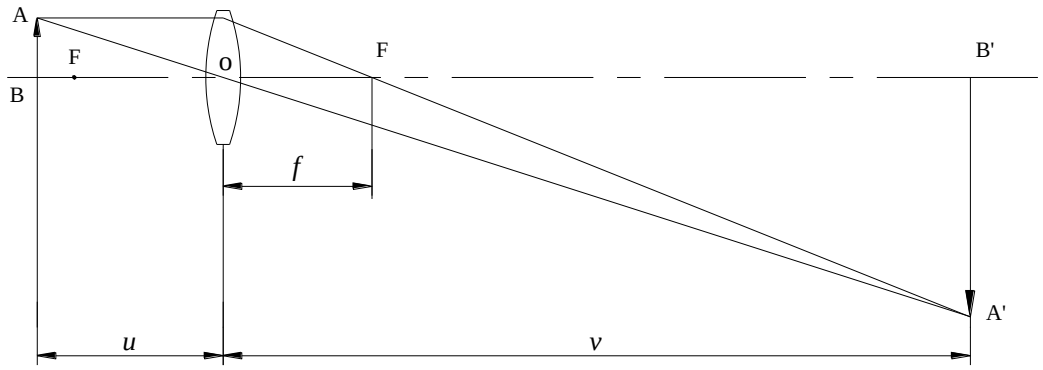


Figure 4.1-1 Lens imaging to achieve an enlarged image

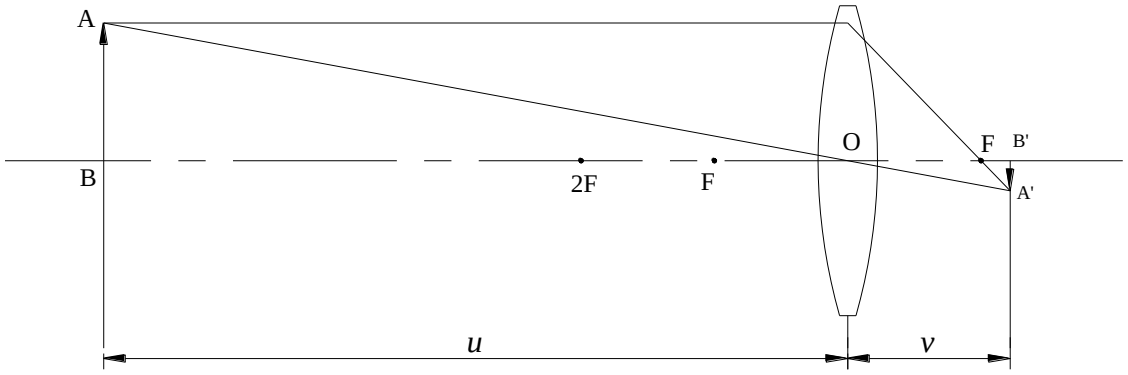


Figure 4.1-2 Lens imaging to achieve a reduced image

Based on the lens imaging equation:

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \tag{4.1-1}$$

where u, v, and f are the object distance, image distance, and focal length, respectively. The focal length of the lens can be derived as

$$f=\frac{uv}{u+v} \tag{4.1-2}$$

When the object is located between one and two focal lengths, i.e. $f < u < 2f$, an inverted and magnified real image is observed beyond two focal lengths, i.e. $v > 2f$ (projector principle, see Figure 4.1-1); while $u > 2f$, v will be $f < v < 2f$, and an inverted and de-magnified real image is formed (camera principle, see Figure 4.1-2).

By measuring the object distance and the image distance, the focal length of the lens can be calculated using Eq. (4.1-2). Repeat measurement several times to improve measuring accuracy. When the object is located far away from the lens ($u >> v$), v can be approximated as f.

4.1.2 Measuring the focal length of a thin convex lens using the auto-collimation method

Illuminating the object screen and placing a flat mirror behind the lens, the light beam passing through the lens will be reflected back to the lens, and then returns to the object screen. Moving the lens along the optical axis back and forth, when the object distance (between the lens and the object screen) equals the focal length, a clear inverted image will be observed on the back side of the object screen. If the flat mirror is mounted on the kinematic lens holder, by adjusting the direction of the mirror, the reflected image can be overlapped to the object and the image is complement to the object, so the object and the image form a complete round. Write down the object and the lens positions, the acquired distance is the focal length of the lens.

4.1.3 Measuring the focal length of a thin convex lens using the Bessel method

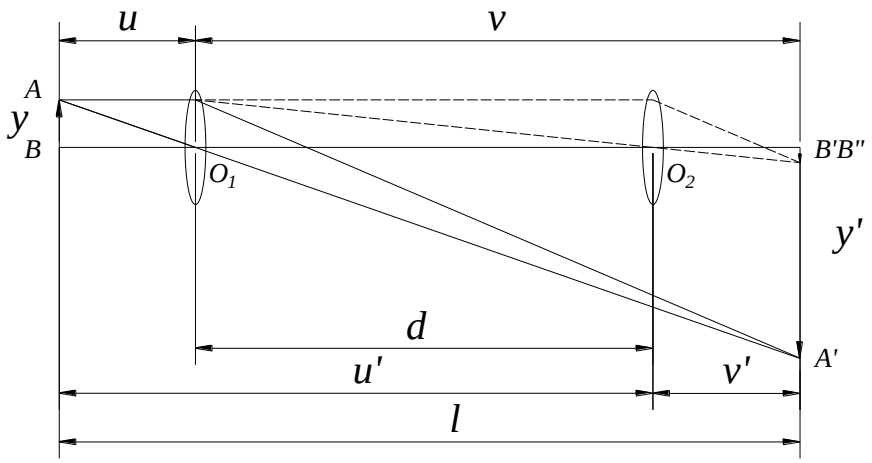


Figure 4.1-3 Schematic of Bessel method

If distance l between the object and the screen is at least four times of the focal length ($l > 4f$), by moving the lens back and forth with the object and the image screen fixed, we can get a clear image twice at different locations as shown in Figure 4.1-3 as (u, v) and (u', v') are the object distance and the image distance of the two images, respectively. If the lens is moved by a distance of d between those two locations, then the focal length f can be derived as:

$$f = \frac{l^2 - d^2}{4l} \tag{4.1-3}$$

4.1.4 Measuring the focal length of a concave lens

Refer to Figure 4.1-4, illuminating object screen *AB* using a white light source, object *AB* will be imaged onto image screen *P* by convex lens L_1 (f =105 mm) to form a reduced image *A'B'*. Write down the position of the image screen, then move it far away from the convex lens. Now insert concave lens L_2 between L_1 and *P* while aligning L_1 and L_2 at same height, and move L_2 back and forth until a clear image *A"B"* is observed on image screen *P*. Write down the position of L_2 at O_2 and the position of *P* at *B"*, hence distance $O_2B"=u_2$ is obtained. Now, the focal length of concave lens L_2 can be calculated from Equation (4.1-2), i.e. $f_2=u_2v_2/(u_2+v_2)$. According to sign rule, f_2 is a negative number.

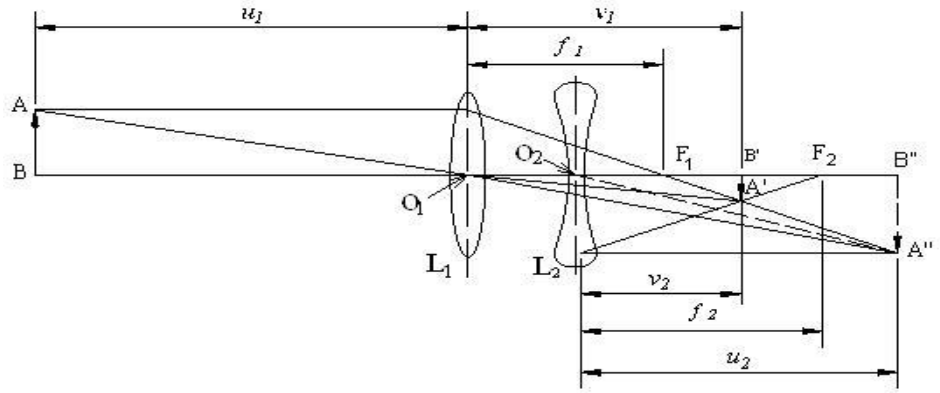


Figure 4.1-4 Schematic of the setup for measurement of focal length of a concave lens

4.1.5 Demonstrating spherical and chromatic aberrations of a convex lens

Using the optical path of Sec. 4.1.2, mount the optical aperture stop on a plate holder (may use an Adapter piece to bring the aperture stop to close to the lens) and respectively place it on-axis and off-axis between the lens and the flat mirror, while measuring focal length f_1 and f_2 under the two cases. The difference between the two results demonstrates the existence and influence of the spherical aberration of the lens.

Remove the aperture stop and respectively use the red and blue filters to cover the front side of the object screen, while measuring the focal length under the two cases, the difference between the two results demonstrates the existence and influence of the chromatic aberration of the lens

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.

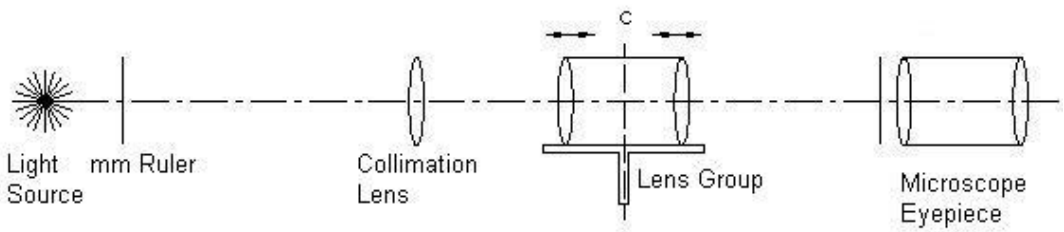


Figure 4.2-1 Schematic of experiment setup

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;
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

$$y_2/y_1 = \Delta / f_o' \qquad (4.3\text{-}1)$$

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.

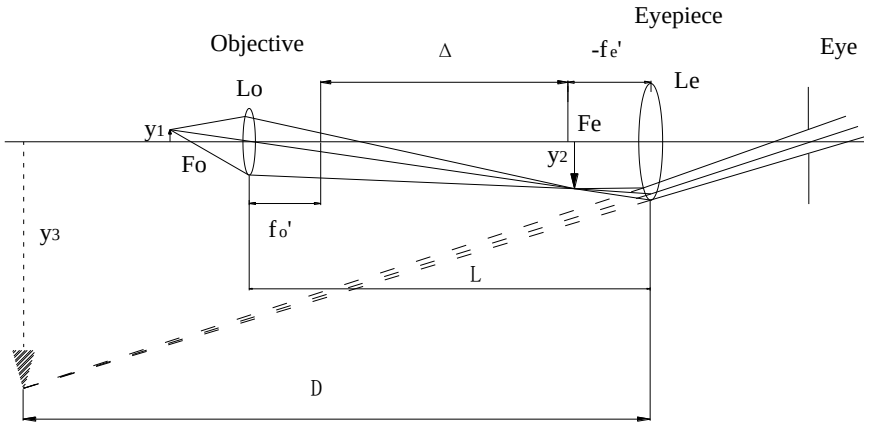


Figure 4.3-1 Schematic of microscope imaging

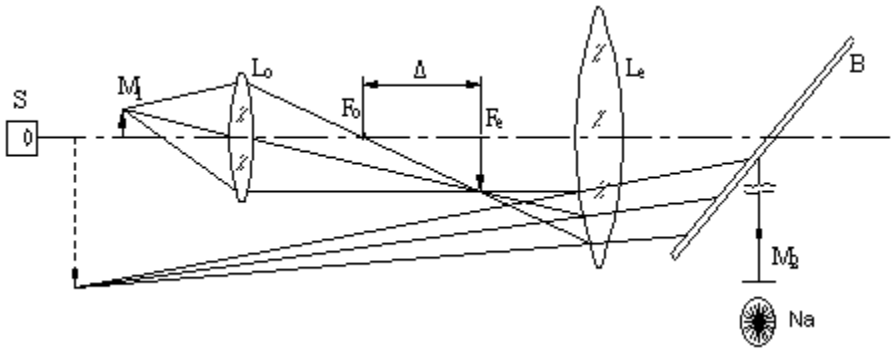


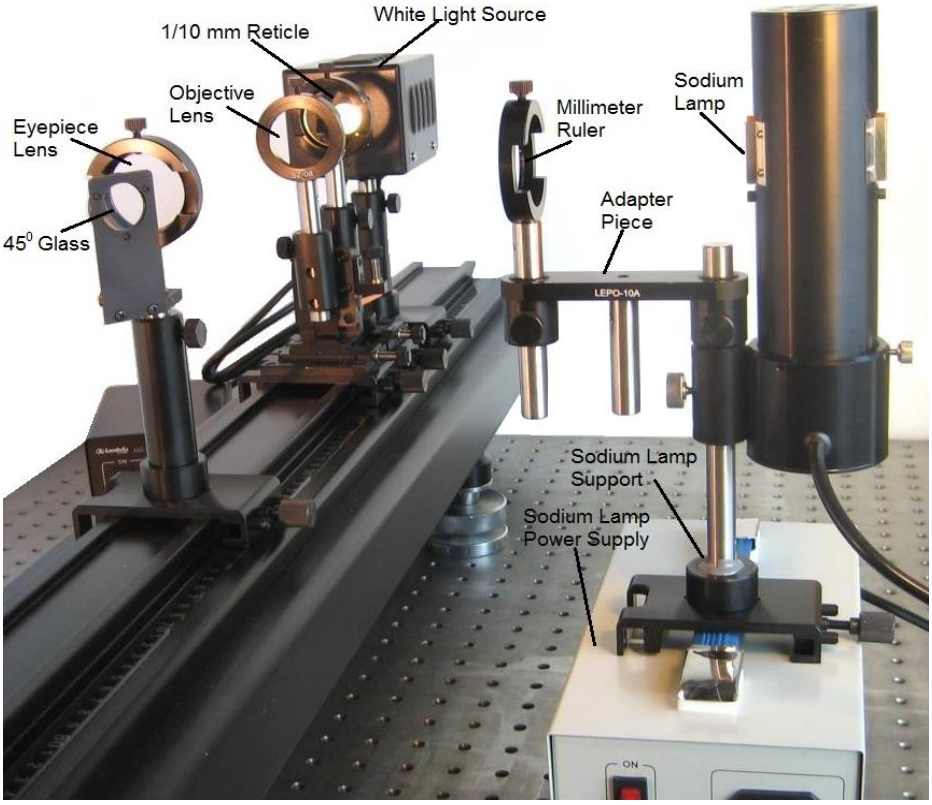
Figure 4.3-2 Schematic of experiment setup

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 millimeter 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* are the object and image angles at the eyepiece and objective lenses, respectively.

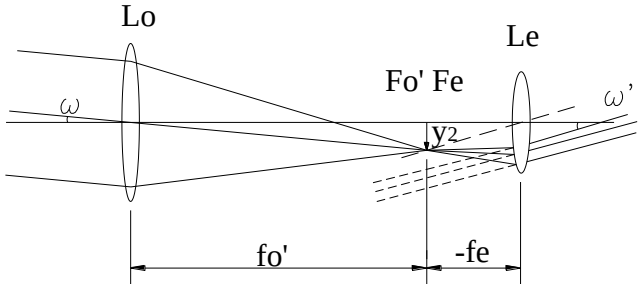


Figure 4.3-3 Schematic of telescope imaging at infinity

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,

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

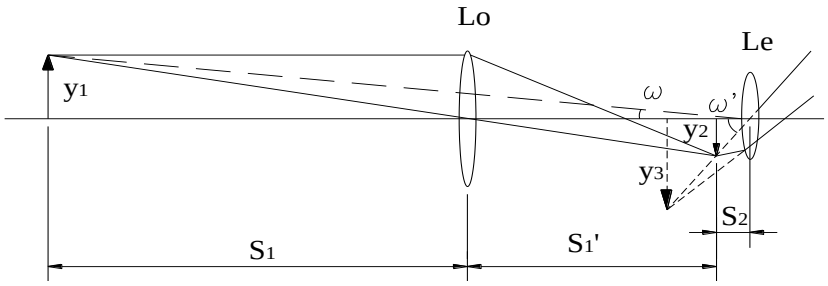


Figure 4.3-4 Schematic of telescope imaging at quasi-infinity.

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.

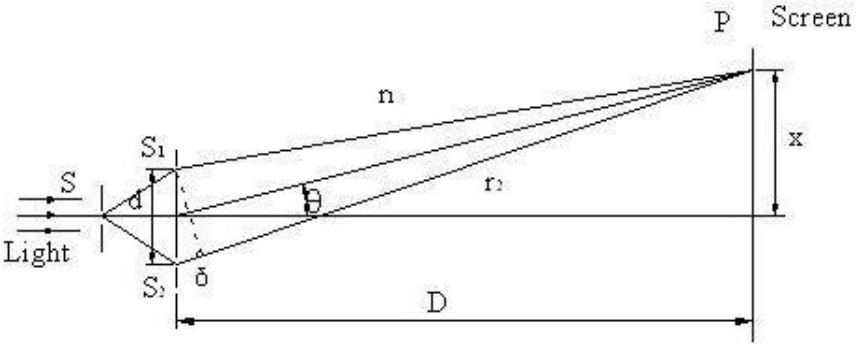


Figure 4.4-1 Schematic of Young's double-slit experiment

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.

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

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.

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

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

$$\Delta x = \frac{D}{d}\lambda \tag{4.4-4}$$

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.

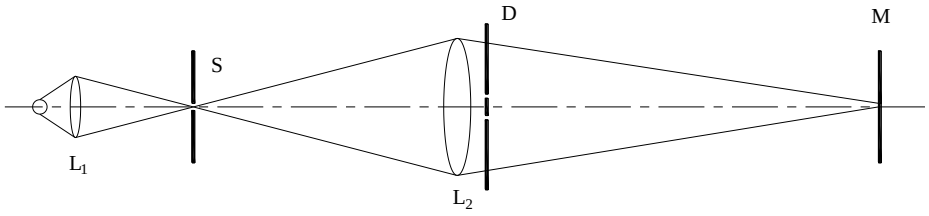


Figure 4.4-2 Schematic of experiment setup

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.

4.5 Interference of Fresnel's biprism

Components required: Sodium lamp with pinhole aperture (1 mm), adjustable slit, biprism, eyepiece of DMM, eyepiece holder, lens holder (2), biprism holder, lenses f'=45 and 190 mm.

Principle

Fresnel's biprism is a prism with a highly obtuse angle as shown in Figure 4.5-1. A ray of light from point source *S* is divided into two overlapping rays by refraction. The prism forms two virtual images, S_1 and S_2 of light source *S*, similar to the two slits in Young's experiment.

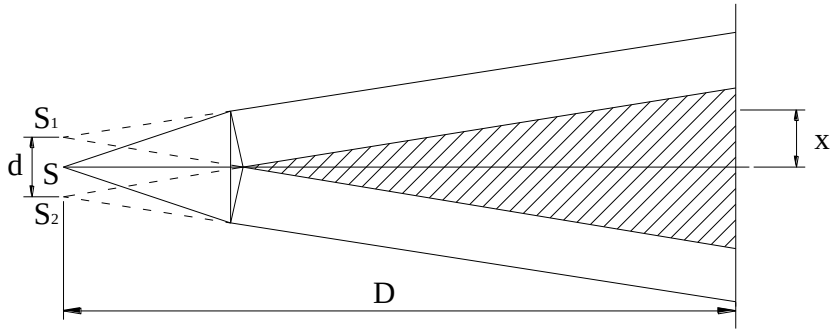


Figure 4.5-1 Schematic of Fresnel's biprism interference

So we have the formulae as follows:

$$d\frac{x}{D} = \pm(2k+1)\frac{\lambda}{2} \quad \text{(Dark interference fringes)} \tag{4.5-1}$$

$$d\frac{x}{D} = \pm k\lambda \quad \text{(Bright interference fringes)} \tag{4.5-2}$$

$$\Delta x = \frac{D}{d}\lambda \tag{4.5-3}$$

where D is the distance between the point source and the viewing screen, x is the vertical distance between the point source and the viewing location on the screen, Δx is the distance between two adjacent dark fringes (or bright fringes), d is the distance between the two virtual images S_1 and S_2, which cannot be measured directly. But if we put a lens behind the biprism and measure the distance between the images of S_1 and S_2 with the eyepiece of a DMM, then d can be calculated.

Experimental Procedure:

1) Refer to Figure 4.5-1, focus the light of a Sodium lamp onto slit S using a lens (f=45 mm), place the biprism behind the slit at a distance of 20 ~ 30 cm; the key to the success of this experiment is to align the edge direction of the obtuse angle of the biprism parallel with the slit direction;
2) Place the lens (f=190 mm) behind the biprism, move the eyepiece to observe the images of the two virtual sources (the distance between the slit and the eyepiece must be larger than 4 times of the focal length of the lens), adjust all related components to achieve symmetrical and uniform images of the two virtual slits;
3) To obtain interval d between the two virtual images generated by the Fresnel's biprism, first measure distance d' between the two real images through the eyepiece, then derive d using the object-image relationship of lens imaging (lens equation); next, remove the lens;
4) Observe biprism interference pattern through the direct measurement microscope, equal-interval bright/dark fringe pairs will be observed;
5) Measure fringe interval Δx between two adjacent fringes using the direct measurement microscope, and measure distance D between the single slit plate and the microscope;
6) Use d, Δx, D and equation (4.5-3), to calculate wavelength λ of the illumination light.

4.6 Interference of double mirrors

Components required: Sodium lamp, adjustable slit, double-mirror, eyepiece of direct measurement microscope, eyepiece holder, adapter piece (extension to both ends), lens holder (2), biprism holder, lenses f'=45 and 150 mm.

Principle

Fresnel's mirrors have a structure as shown in Figure 4.6-1. Two plane mirrors M_1 and M_2 are oriented with a very small variable angle. Light from point source S is incident on the two mirrors, and the reflection forms two virtual images S_1, S_2 of S, which act as coherent sources.

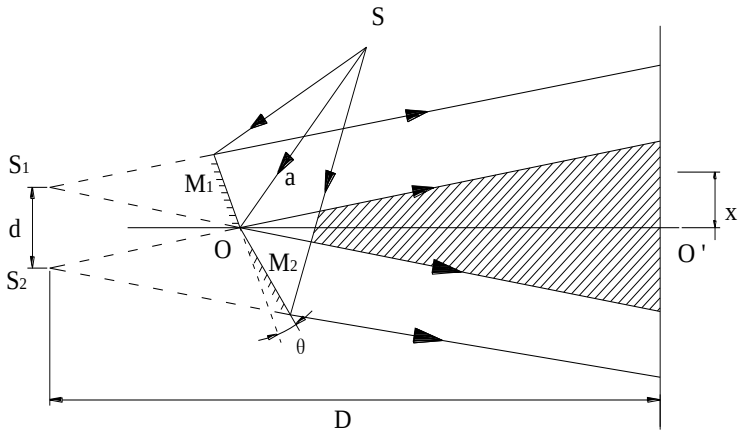


Figure 4.6-1 Schematic of Fresnel's double mirror interference

If $SO = a$, then $S_1O = S_2O = a$. The distance between S_1 and S_2 is

$$d = 2a\sin\theta \tag{4.6-1}$$

where θ is the angle between the mirrors.

As in Young's experiment, we get the formulae:

$$d\frac{x}{D} = \pm(2k+1)\frac{\lambda}{2} \quad \text{(Dark interference fringes)} \tag{4.6-2}$$

$$d\frac{x}{D} = \pm k\lambda \quad \text{(Bright interference fringes)} \tag{4.6-3}$$

$$\lambda = \frac{d}{D}\Delta x = \frac{2a\sin\theta}{a\cos\theta + OO'}\Delta x \approx \frac{2a\theta}{a + OO''}\Delta x \tag{4.6-4}$$

Experimental Procedure:

1) The key to the success of this experiment is to align the directions of the two mirrors by adjusting the three screws on the back of one mirror to guarantee the normal of two mirrors in one plane with a small intersection angle between them;
2) To fulfil the above condition, a small laser beam is used to simultaneously illuminate the adjacent area of the two mirrors (half beam on each mirror), and two reflected beam spots can be observed on a far field screen. By fine adjustment of the three screws on the back of one mirror, the input beam and the two reflected beams are in a one plane. The intersection angle θ of the two mirrors can be obtained by calculating the ratio of the two beam spots on the screen and the distance between the screen and the mirrors (here we align them at about 0.5°);

3) Refer to Figure 4.6-1, place the Sodium lamp at one end of the optical rail, mount the lens (f'=45 mm) and the adjustable slit onto the two ends of an adapter piece;

4) Focus the Sodium light onto the slit by the lens (f'=45 mm), and rotate the single slit direction to align it parallel to the mirrors' intersection;

5) Use the eyepiece of direct measurement microscope to observe the interference pattern that has equal-interval bright/dark fringe pairs; Note: since the main light beam will slightly deviate from the central axis of the optical rail after the double-mirror, we mount the eyepiece to an adapter piece and then mount to a carrier, so that it can rotate around the carrier to achieve a proper observation angle to follow the main light beam (i.e. the interference pattern).

6) Measure fringe interval Δx between two adjacent fringes using the direct measurement microscope and path length D from the single slit to the microscope via the intersection of the two mirrors;

7) To obtain interval d between two virtual images S_1, S_2 of slit light source S, multiply the double angle of two mirrors 2θ, measured in step 2, by distance a between the single slit and the mirrors;

8) Use d, Δx, D and equation (4.6-4) to calculate wavelength λ of the illumination light.

4.7 Interference of Lloyd's mirror

Components required: Sodium lamp, adjustable slit, Lloyd's mirror, plate holder, eyepiece of direct measurement microscope, eyepiece holder, adapter piece (extension to both ends), lens holder (2), and lenses f'=45 and 150 mm.

Principle

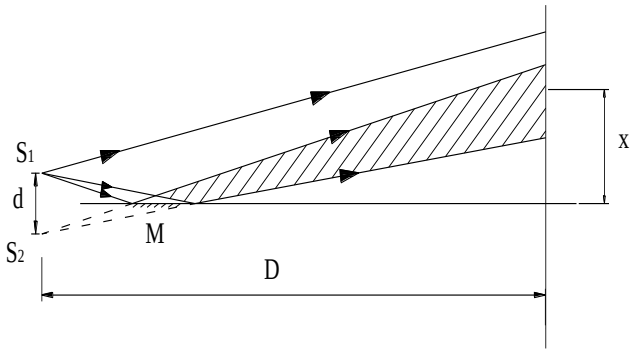


Figure 4.7-1 Schematic of Lloyd's mirror interference

The Lloyd's mirror used in this experiment is a piece of black glass M. As seen in Figure 4.7-1, a point source (S_1) is placed close to glass M, so that light is reflected at nearly grazing incidence. The coherent sources are the primary source (S_1) and its virtual image (S_2) formed by the glass. The bisector of S_1 and S_2 then lies in the plane of the mirror surface, as shown in Figure 4.7-1.

Similar to Fresnel's mirror experiment, we have the expression:

$$\lambda = \frac{d}{D}\Delta x \qquad (4.7\text{-}1)$$

where λ is the wavelength of the light source, D is the distance between the source and the viewing screen, d is the distance between the primary point source and its virtual image formed by the mirror, and Δx is the interval between two adjacent dark fringes (or bright fringes) on the screen.

Experimental Procedure:

1) Refer to Figure 4.7-1, place the Sodium lamp at one end of the optical rail, mount the lens (f'=45 mm) and the adjustable slit onto the two ends of an adapter piece,
2) Focus the Sodium light onto the slit by the lens (f'=45 mm), and rotate the single slit direction to align it parallel to the edge of the Lloyd's mirror;
3) Let one portion of the beam exiting from the slit illuminate on the glass surface, while the other portion of the beam propagates passing the side of the glass edge;
4) Slowly move the Lloyd's mirror close to the centre of optical axis from one side (note: mount the Lloyd's mirror on the x-translation carrier), let the input light sweep across the Lloyd's mirror. Behind the mirror, using one eye to observe the direct and the reflected beams, slit S and its virtual image S' (by Lloyd's mirror) will be observed;
5) Rotate the single slit to align S and S' parallel, fix Lloyd's mirror by setting the interval of S and S' at approximately 2 mm;
6) Use direct measurement microscope to observe Lloyd's mirror interference pattern, and equal-interval bright/dark fringe pairs will be observed;
7) Measure fringe interval Δx between two adjacent dark (or bright) fringes using direct measurement microscope and distance D between single slit and microscope;
8) To obtain interval d between light sources S and S', put lens L_2 (f' = 190 mm) behind Lloyd's mirror to form the two light sources into real images, and move the direct measurement microscope to the real image plane to measure distance d' between the two real images. Derive d by using the lens equation;
9) Use d, Δx, D and equation (4.7-1) to calculate wavelength λ of the illumination light.

4.8 Fraunhofer diffraction of a single slit

Components required: Sodium lamp, adjustable slit (2), eyepiece of direct measurement microscope, eyepiece holder, lens holder (2), and lenses f'=150 and 225 mm.

Principle

Fraunhofer diffraction is the diffraction of parallel light (the so-called far-field diffraction). It can be simply explained using Huygens' Principle. As shown in Figure 4.8-1, a plane wave is incident upon a long, narrow slit and there are an infinite number of secondary sources that emit spherical waves across the aperture. For a particular observation point, each source has a different optical path that introduces a phase relationship between the waves that are emitted across the aperture. The resultant sum becomes an integral over the aperture, thus a simple

relationship between the "angle of diffraction" and the light intensity in the observation plane can be derived.

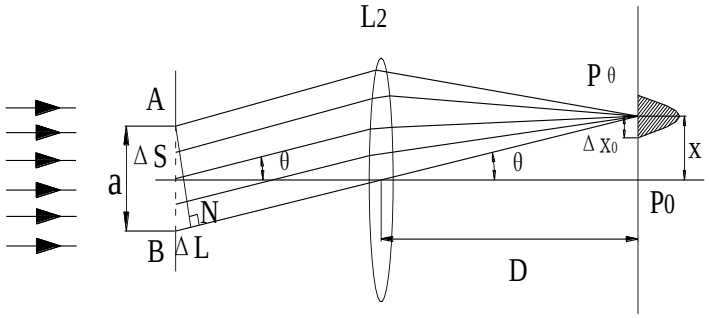


Figure 4.8-1 Schematic of Fraunhofer diffraction from single slit

In the observation plane, we may write:

$$I = I_0 \frac{\sin^2(\beta)}{\beta^2} \tag{4.8-1}$$

where $\beta = \frac{2\pi}{\lambda}\frac{a}{2}\sin\theta$, and a is the slit width.

When β=nπ where n is an integer, a minimum diffraction intensity occurs. Then, sinθ=λ/a is the condition for the first minima. This relationship can be used to calculate the slit width.

Experimental Procedure:

1) Refer to Figure 4.8-1, align all components at the same height on the rail;
2) Put lens L_1 behind single slit S_1 at a distance of 150 mm (focal length of L_1), the collimated beam illuminates on another single silt S_2;
3) Put lens L_2 behind single slit S_2 to focus the diffracted light;
4) Aim direct measurement microscope to the back focal plane of lens L_2, where, bright/dark diffraction fringes will be observed;
5) Measure the width of the central fringe (Δx_0) using the microscope;
6) Calculate the slit width by $a = \frac{2\lambda f'}{\Delta x_0}$ at λ = 589.3 nm;
7) Directly measure the slit width using the microscope, and compare this result with the calculated result in step 6.

4.9 Fraunhofer diffraction of a single circular aperture

Components required: Sodium lamp with 1.0 mm aperture, 0.3 mm diffraction pinhole, eyepiece of direct measurement microscope, eyepiece holder, lens holder (2), and lenses f'=70 and 225 mm.

Principle

A slit can produce a diffraction pattern with bright and dark fringes parallel to the slit. The size of diffraction patterns produced depends on the shapes of the apertures used. For a circular hole of diameter *d*, the diffraction pattern consists of a series of concentric dark and bright rings. The pattern of the intensity distribution can be calculated in the same way as for a single slit.

The direction of the first dark ring with respect to optical axis is given by:

$$\theta \approx \sin\theta = 1.22\frac{\lambda}{d} \tag{4.9-1}$$

where d is the diameter of the aperture, and θ is the angle of observing direction with respect to the incident direction.

Experimental Procedure:

1) Place the diffraction pinhole far away from the light source (approximately 600 mm), approximately satisfying the condition for Fraunhofer diffraction;
2) Put a lens behind the pinhole to focus the diffracted light;
3) Aim the direct measurement microscope to the back focal plane of the lens, where bright/dark diffraction rings will be observed;
4) Measure Airy disk diameter d_1 using the microscope;
5) Calculate aperture diameter by $d = \frac{1.22\lambda f'}{d_1}$ at λ = 589.3 nm;
6) Directly measure the aperture diameter using the microscope, compare this result with the calculated result in step 5.

4.10 Examining light polarization

Components required: white light source, adjustable slit, optical goniometer, black glass plate, polarizer (2), ¼ waveplate (632.8 nm), polarizer (waveplate) holder (3), lens holder, He-Ne laser, laser holder, iceland crystal with holder, beam expander, lens f'=150 mm.

Principle

For light emitted from a natural light source, the direction of the electric vector E is random due to the random thermal motion of molecules. Natural light becomes partially polarized through reflection, refraction or absorption of some media, whose electric vector is dominated in one specified direction. If the electric vector is completely constrained in one direction (or in one plane along the propagation direction), it is called as plane polarized light or linearly polarized light. If the trajectory of the end of the electric vector forms an oval or a circle in the plane perpendicular to the direction of light propagation, the light is called elliptically polarized light or circularly polarized light.

a. Polarization by reflection and the Brewster angle

When natural light incidents on the interface of two media (e.g. air and glass), both the reflected and the transmitted (refracted) light rays become partially polarized.

Experimental Procedure:

Sequentially place white light source, lens (f'=150 mm), adjustable slit, and optical goniometer on the optical rail, align them at the same height, and let the filament of the light source locating on the front focal point of the lens (the interval between the two carriers is about 162 mm). After passing through the slit, the approximately parallel beam will hit to the disc of the optical goniometer, and leave a light track on the surface of the disc. Vertically mount the black glass along the 90°-90° line on the disc firmly. Then, place the polarizer holder mounted with polarizer *A* to the hole on the arm of the goniometer assembly, as seen in Figure 4.10-1. Let the light beam incident on the glass surface at an arbitrary angle, rotate polarizer *A* to check the polarization status of the reflected beam.

When rotating *A*, the transmitted light will vary alternatively between bright and dark, indicating that the reflected beam is partially polarized. When the incident angle is close to 56°30', the reflected light can be almost extinguished. This incident angle is called the Brewster Angle. Since the vibration plane of this linearly polarized light is perpendicular to the incident plane, the polarization direction of polarizer *A* can be determined.

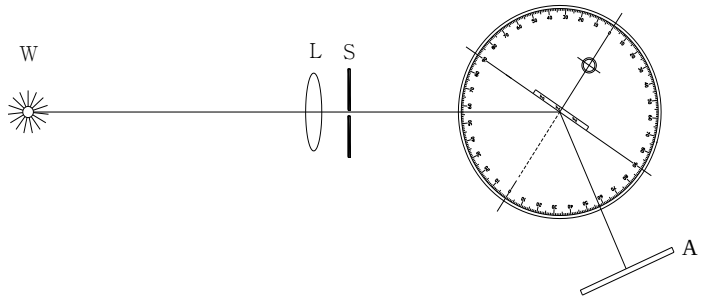


Figure 4.10-1 Schematic of the setup for generating polarized light by reflection.

b. Polarization by dichroic material

Some materials have selective absorption to the polarization components of polarized light. Absorption may be stronger at one vibration direction, but weaker in the orthogonal direction. This is the dichroic characteristic of the materials. An H-type polarizer is created by attaching iodine to the hydrocarbon chain of one stretched long chain polymer film. A larger number of parallel aligned iodine-containing long-chain molecules form a grid structure that has a small spacing of less than light wavelength. Since the iodine atom has highly conductivity, the electric field component parallel to the grid is easier to be absorbed, while the vertical component is easier to transmit. Therefore, the dichroic film can be used to check the polarization status of a light beam.

Place two polarizers onto the optical rail with the one closer to the light source for the generation of polarized light, and the one behind as an analyzer. Rotate the analyzer, the intensity variation of the output light can be observed.

c. Birefractive characteristic of crystal

Put an iceland spar on a piece of printed paper, and we will see two distinct images of words. One image will remain fixed as the crystal is rotated, and the light ray through the crystal is

called "ordinary ray" since it behaves just as a ray through a glass. However, the other image will rotate with the crystal, tracing out a small circle around the ordinary image. This light ray is called "extraordinary ray". This is the phenomenon of birefringence. See Figure 4.10-2.

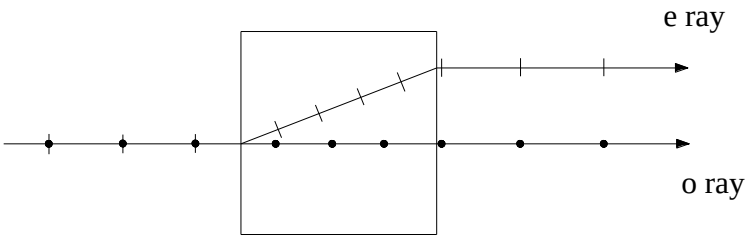


Figure 4.10-2 Schematic of birefringence

Place the iceland crystal with holder on the optical rail, illuminate the small hole in front of the crystal with a white light source, observe the transmitted light behind the iceland crystal with naked eyes, rotate the mount of the crystal, determine the “ordinary ray” and the “extraordinary ray” according to their intensity variations. Finally, use an analyzer with known polarization direction to determine the polarization directions of the o-ray and the e-ray.

d. Elliptically polarized light

Create a linearly polarized beam using the reflection method discussed above, i.e. an expanded laser beam passes a slit to be incident on the glass at the Brewster angle. See Figure 4.10-3, place quarter-wave plate *Q* on the goniometer arm to create elliptically polarized light. Mount analyzer *A* and white screen *C* on the two ends of an adapter piece and place them behind analyzer *A*. Rotate the analyzer while observing the dark and bright intensity variation of the transmitted light. At the dark location, the analyzer direction is the minor axis direction of the ellipse.

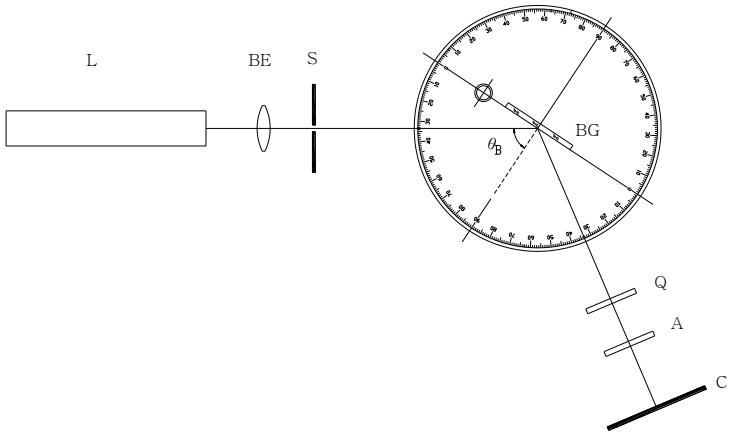


Figure 4.10-3 Schematic of experiment setup

e. Circularly polarized light

Place a He-Ne laser at one end of the optical rail, expand the laser beam using a beam expander, place two polarizers in the optical path of the expanded laser beam on the other end of the optical rail. Rotate one of the two polarizers to get output light extinguished, this means the axes of the two polarizers are perpendicular. Insert a quarter-wave plate between the two polarizers, and

rotate it until the output light extinguished again. Further rotate the quarter-wave plate by 45°, the light behind the quarter-wave plate is now circularly polarized. Next, rotate the analyser (the polarizer following the waveplate), the intensity of the output light will be constant.

4.11 Effect of optical activity

Components required: Sodium lamp (with ground glass on window), polarizer with rotary holder (2), liquid cell with holder, lens holder with lens f'=150 mm, glucose powder (user supply), distilled water (user supply), and measuring cup (user supply).

Principle

When linearly polarized light passes through certain solid substances or solutions, the plane of polarization of the light rotates by a certain angle. This phenomenon is called the effect of optical activity and the optical rotatory angle is called the specific rotation of the substance. The specific rotation of a solution depends on a number of parameters such as the substance in the solution, the concentration of the solution, the sample path length, the temperature of the solution, and the wavelength of the light. If other parameters are fixed, then the specific rotation, φ, is linearly proportional to the concentration of the solution, ρ, in unit of g/cm^3, and the sample path length, l, unit decimetre (dm), as

$$\varphi = \alpha \cdot \rho \cdot l \tag{4.11-1}$$

where α is a coefficienct representing the polarization rotation power of the substance in the solution, in unit of degree.cm^3/dm.g.

Experiment:

Place the Sodium lamp at one end of the optical rail, place the lens (f'=150 mm) on the rail at a distance of about 150 mm away from the lamp window to form an approximately parallel beam. Put two polarizers in the optical path behind the lens, and rotate them to achieve light extinction as observed behind the second polarizer (analyzer). Next, mount the liquid tube (filled with prepared glucose solution) between the two polarizers, observe the output light, and rotate the analyzer to achieve light extinction again.

Using Eq. (4.11-1), from the measured rotation angle φ and the cell length l, if the solution concentration ρ is known, the polarization rotation power α of glucose solution can be derived, or, if α is known, the concentration ρ can be acquired. Note: α is temperature dependent, so it needs to be modified from a standard value at 20 °C by approximately -0.02°/°C.

After experiment, clean the liquid tube.

4.12 Abbe imaging principle and optical spatial filtering (LEOI-6B only)

Components required: He-Ne laser, laser holder, beam expander, grating, biprism holder, flat mirror, lens holder (4), lenses f'=150 and 190 mm, adapter piece, ground glass screen, 2-D grating, plate holder, paper plate (prepared by user), spatial filter set (directional, low-pass, high-pass, band-pass, and small aperture), transmissive character with grid, adjustable slit.

Principle

Abbe's theory assumes that an object to be imaged can be decomposed into a number of elemental gratings - each grating diffracts light at an angle that is a function of the grating period and the groove orientation. The diffracted beams are plane waves that can be focused by a lens to form diffraction patterns in the back focal plane of the lens, as seen in Figure 4.12-1. These diffraction patterns in turn act as sources of waves that propagate from the focal plane to the image plane where the image is produced. Simply speaking, it can be considered in two steps: the first step is to resolve the information, and the second is to synthesize the information.

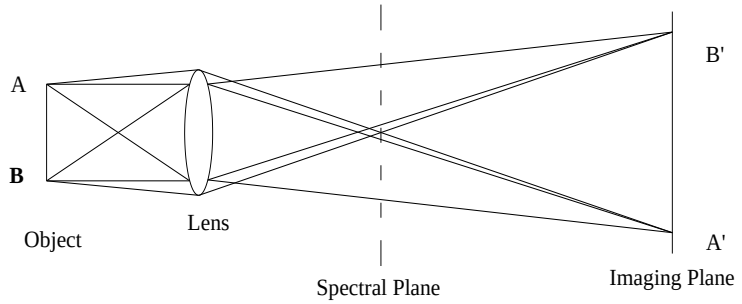


Figure 4.12-1 Schematic of Abbe's imaging

a. Examine the two-step imaging principle

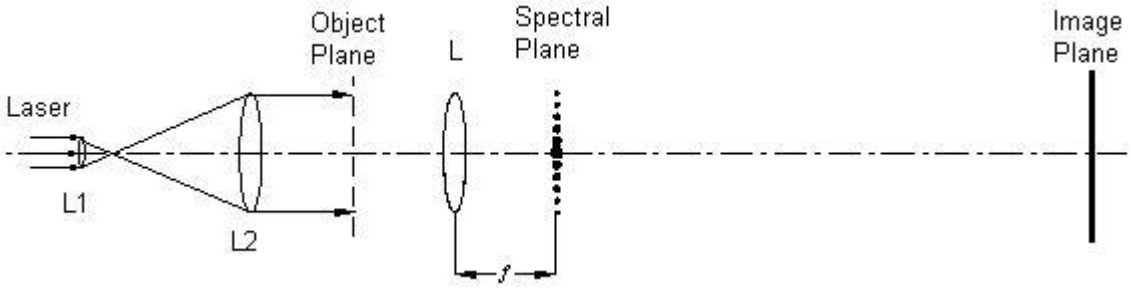


Figure 4.12-2 Schematic of the setup for examining two-step imaging principle

1) Refer to Figure 4.12-2, align all components at the same height along the rail;
2) Use L_1 (f'=4.5 mm) and L_2 (f'=150 mm) to construct an expanded beam to illuminate a transmission grating (1-D grating) whose grating grooves are in the vertical direction;
3) Put a white screen or a ground glass screen 2 m away from the grating, move transform lens L (f'=190 mm) back and forth to form a clear grating image on the screen;
4) Move the screen at approximately 190 mm behind lens L, a row of clear diffraction spots can be observed on the screen. This is the spatial spectrum of the object.
5) Since the focal length of lens L and the wavelength of the light are known, by measuring distance x' (or y' for a 2-D case) between the zero-order and a higher-order spectral

spots on the screen, the spatial frequencies of these orders can be calculated using the formula: $v_x = \frac{x'}{\lambda \cdot f}$, and $v_y = \frac{y'}{\lambda \cdot f}$.

b. Further examine the two-step imaging principle

In the optical path set above, place the adjustable slit on the spectral plane to allow different spectral components to pass the slit while observing the image on the image plane:

1) Replace the 1-D grating with a 2-D grating, an enlarged 2-D grating image is observed on the image plane. Adjust the direction of the 2-D grating to get horizontal and vertical grating lines on the image plane.
2) Move the ground glass screen to spectral plane, a 2-D spectral spot array will be observed. See Figure 4.12-3.

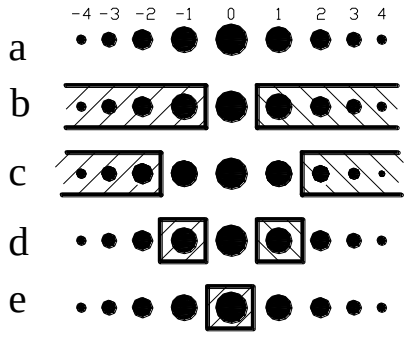


Figure 4.12-3 Schematic of 2-D spectral spot array

3) Measure the distance between the zero-order spot and a higher-order spot, similar to the above 1-D case, the spatial frequency of the corresponding spot can be calculated.
4) Place a small aperture or an adjustable slit on the spectral plane and rotate the slit to pass spectral spots at different directions as seen in Figure 4.12-4, while observing the image changes on the image plane.
5) Analyse and explain the observed phenomena.

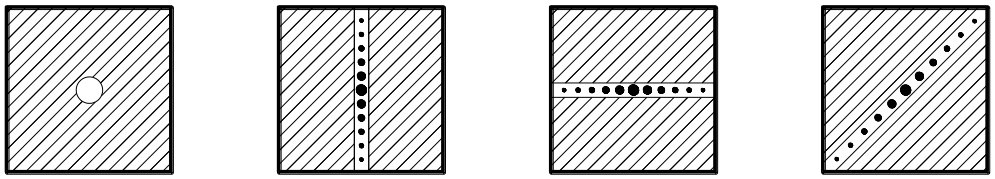


Figure 4.12-4 Cases of spectral filtering

c. Low-pass and high-pass filtering principle

There are several frequently used filters shown in Figure 4.12-5, where **A** is a low-pass filter to block higher spatial frequency components; **B** is a high-pass filter that blocks low frequency components, and **C** is a band-pass filter that allows a range of frequency components to pass.

Replace the 2-D grating with a transmissive character object that has a 2-D grid on it. According to the above filtering results, find a filtering method to eliminate the grid on the character in the final image.

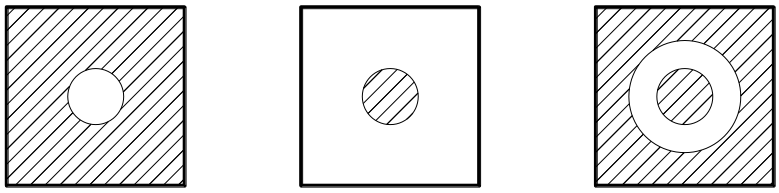


Figure 4.12-5 Low-pass, high-pass and band-pass filters

4.13 Pseudo-color encoding, theta modulation and color composition (LEOI-6B only)

Components required: white light source, theta-modulation plate, plate holder, ground glass screen, lens holder (3), lenses f'=150 and 190 mm, paper plate and a pin.

Principle

Theta modulation is an application of Abbe's imaging. The object used is a special grating that is composed of three groups of grating reticles. The angle among them is 120° and they represent the sky, the sun and the ground, respectively. Fourier spectrum of such a grating is shown in the middle of Figure 4.13-1.

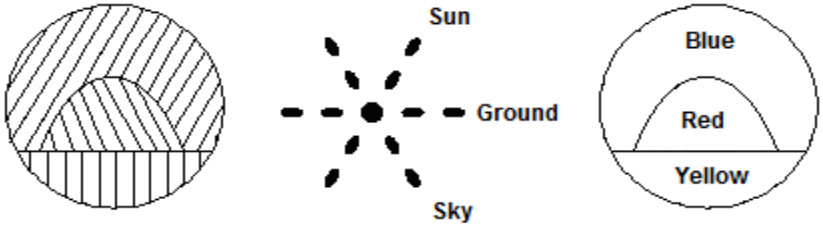


Figure 4.13-1 Schematic of Theta modulation plate

We can use the filter to select the spectrum we want. We can get 'the blue sky', 'the red sun' and 'the yellow ground'. It is also called pseudo-color encoding.

Experimental Procedure:

Note: This experiment is recommended to be carried out in a less bright environment.

1) Refer to Figure 4.13-2, align all components at the same height on the optical rail;
2) Place the Bromine-Tungsten lamp at the front focal point of lens L_1 to generate a collimated beam and illuminate onto a θ-modulation plate. (Remove the ground glass plate and use the filament as the source);

3) Place screen *P* about 0.8 m away from the θ-modulation plate, place transform lens L_2 between the θ-plate and the screen, then move L_2 back and forth to form a clear θ-modulation plate image on the screen;

4) Place a plain paper plate at the back focal plane of L_2 (Fourier plane). The spatial spectrum of the object can be observed as similar to the middle image shown in Figure 4.13-1;

5) Using a sharp pin, pierce holes on the paper. Only use the first order spectrum as the zero-order spectrum would produce the complete image. As each hole is made, observe the associated image on the screen. Once the orientations of the Fourier spectral spots with the corresponding portions of the object are determined, replace the paper plate with a new one;

6) Using the pin carefully now, pierce holes at the relevant places on the tiny spectra, i.e. filtering a single color through to observe the sky as blue, the sun as red, and the ground as yellow (or your own selection of colors).

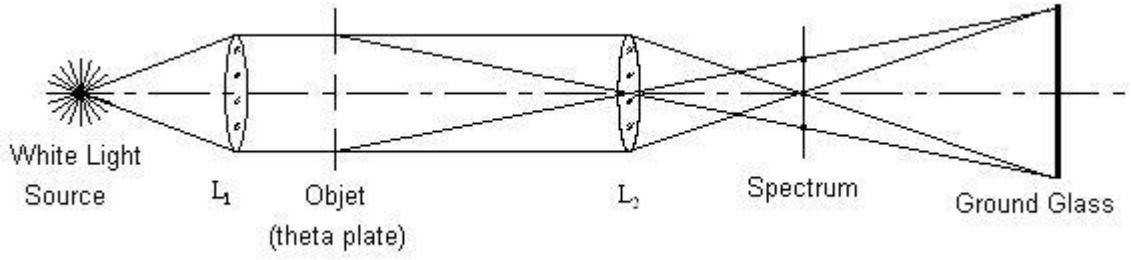


Figure 4.13-2 Schematic of experiment setup

5. Laser Safety and Lab Requirements

Warning: the He-Ne laser in this kit is a class IIIa laser. Avoid direct eye exposure to the laser beam!

Follow the corresponding laser safety guidelines based on AS/NZS 2211.1:1997 and other lab instructions about optical components etc.