### 3.21 Grating Monochromator

**Objective:**

Understand the principle of a grating monochromator, and learn how to assemble a Littrow-type grating spectrometer

**Experimental Setup**

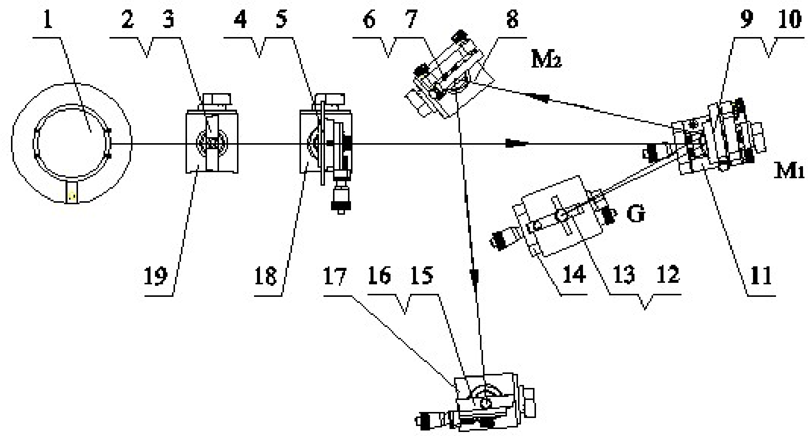


Figure 21-1 Schematic of experimental setup

1: Mercury Lamp with Aperture Hole (LLE-1)
2: Lens $L_1$ ($f'$ =50 mm)
3,15: Lens Holder (SZ-08)
4,16: Adjustable Slit (SZ-27B)
5: Rotatory Lens Holder (SZ-06A)
6: Flat Mirror $M_2$
7,10: Two-Axis Mirror Holder (SZ-07)
8,19: Magnetic Base (SZ-04)
9: Spherical Mirror $M_1$ ($f'$ = 300 mm)
11,14: Two-Axis Stage (SZ-02)
12: Grating Table (SZ-10)
13: Flare grating $G$ (1200 lines/mm)
17,18: Z-adjustable Stage (SZ-03)

*Others needed: Plate Holder (SZ-12) and White Screen (SZ-13)

**Principle**

Using the characteristics of a blazed grating, we can get the spectral lines of a light source. The principle of a blazed grating is almost the same as the last experiment, as shown in Figure 21-2.

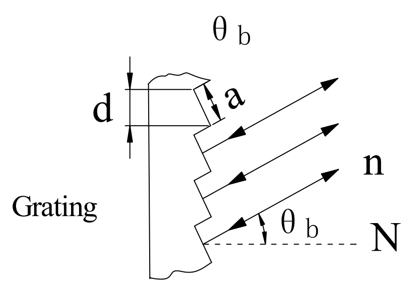


Figure 21-2 Schematic of blazed grating diffraction

The blazed wavelength of the $k_{th}$ order is given by:

$$2d \sin\theta_b = k\lambda_{kb} \quad k=1, 2, 3... \tag{21-1}$$

The structure of a grating monochromator is shown below in Figure 21-3.

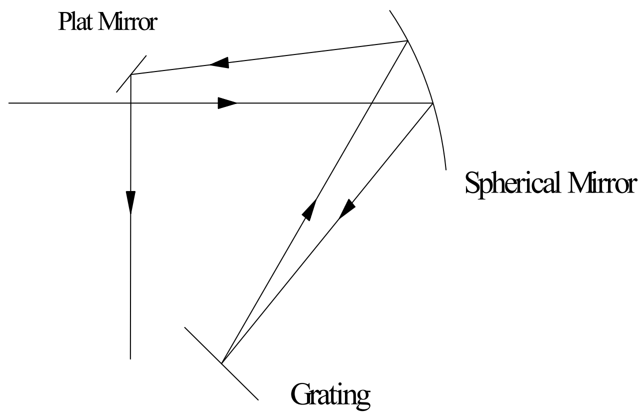


Figure 21-3 Schematic of grating monochromator

**Experimental Procedure:**

Note: This experiment is recommended to be carried out in dark environment.

1) Refer to Figure 21-1, align all component in same height and let the primary plane of the system parallel to the table;
2) Focus the light source on the adjustable slit (slit width > 0.5 mm) using lens $L_1$;
3) Set each component according to Figure 21-1, check the light field on $M_2$, $M_1$ and $G$, make sure no part of the light path is blocked and the central portions of these components are illuminated; set the distance between the grating and the spherical mirror to be about 200 mm.
4) Let the incident beam on $M_1$ and the output beam from $M_1$ have a minimum intersection angle (approximately Littrow-style);
5) Use a white screen to find the optimal focusing position of the output spectrum, then replace the white screen with an adjustable slit at about 0.05 mm width;
6) Rotate the grating, spectral lines of the Mercury lamp will exit from the slit sequentially.

### 3.22 Analysing Polarization Status of Light Beams

**Objective:**

Observe polarization phenomena, analyze polarization status of an input beam, generate the desired polarization status, and determine the axis direction of a polarizer

**Experimental Setup**

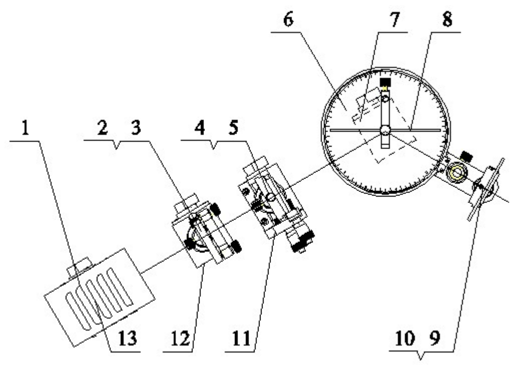


Figure 22-1 Schematic of experimental setup

1: Bromine Tungsten Lamp (LLC-3)
2: Lens ($f'$ =150 mm)
3: Two-Axis Mirror Holder (SZ-07)
4: Adjustable Slit (SZ-27B)
5: Lens Holder (SZ-08)
6: Optical Goniometer (SZ-47)
7,12: Z-adjustable Stage (SZ-03)
8: Lloyd Mirror (black glass)
9: Polarizer
10: Rotatory Lens Holder (SZ-06A)
11: Two-Axis Stage (SZ-02)
13: Magnetic Base (SZ-04)

* Other parts needed: low-pressure sodium lamp (LLE-2), He-Ne laser (LLL-2), quarter-wave plate, iceland crystal (SZ-48), beam expander ($f'$ = 4.5 mm), and two-axis mirror holder (SZ-07).

**Principle**

**a) Brewster's Angle**

When unpolarized light travels from a transparent medium with a refractive index $n_i$ to another one with a higher refraction index $n_t$, part of the light is refracted into the second medium while the other part of the light is reflected back into the first medium, as shown in Figure 22-2.

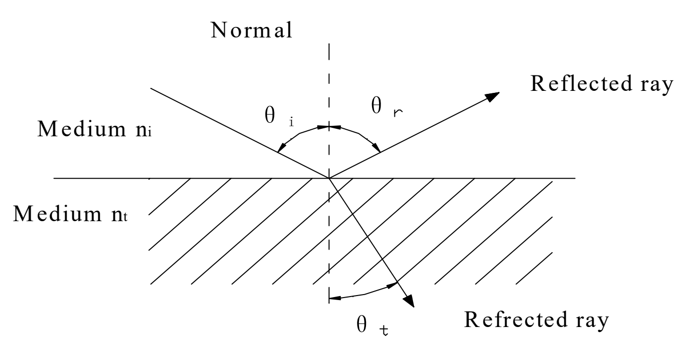


Figure 22-2 Reflection and refraction of light between two media

If the angles of incidence and refraction are $\theta_i$ and $\theta_t$, respectively, the following condition exists, known as Snell's law

$$n_i \sin\theta_i = n_t \sin\theta_t \tag{22-1}$$

According to Sir David Brewster, at a specific angle of incidence, $\theta_b$, called Brewster's angle, the reflected ray and the refracted ray are perpendicular to each other, so the sum of the incident angle and the refractive angle is 90° as

$$\theta_b + \theta t = 90°\text{, namely } \theta_t = 90° - \theta_b \tag{22-2}$$

By substituting equation (22-2) into equation (22-1), we get

$$\begin{aligned} n_i \sin\theta_b &= n_t \sin(90° - \theta_b) = n_t \cos\theta_b \\ \tan\theta_b &= \frac{n_t}{n_i} \end{aligned} \tag{22-3}$$

Then the Brewster's angle is:

$$\theta_b = \arctan\frac{n_t}{n_i} \tag{22-4}$$

**b) Birefringence**

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 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.

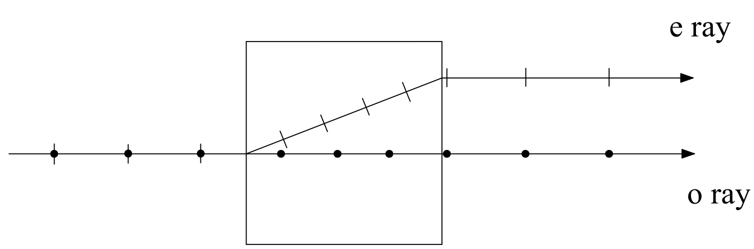


Figure 22-3 Schematic of birefringence

**c) Malus's Law**

When a light ray passes through a polarizer, then another polarizer, called analyzer, the transmitted light intensity $I(\theta)$ leaving out of the second polarizer, is given by Malus's Law

$$I(\theta) = I_0 \cos^2\theta \tag{22-5}$$

Where $I_0$ is light intensity incident on the first polarizer, $\theta$ is the angle of two polarizer axes.

**Experimental Procedure:**

1) Measure Brewster's angle and determine the polarization direction of a polarizer

   Let the filament of the Tungsten light source locating on the front focal plane of the lens to create a collimated beam (the distance between the two magnetic bases is about 162 mm). After passing through the slit, the beam is incident onto the black glass at the center of the goniometer disk and light leaves a track along the radial direction on the disk. Rotate the goniometer disk, let the beam have a specific angle incident on the black glass. Then rotate the polarizer one full turn, observe the beam behind the polarizer and let the polarizer stop at the darkest angle position. Then rotate the goniometer disk and the polarizer alternatively, let the observed light becoming dark and dark till the darkest (finely adjust the polarizer angle at the same time). Finally, the polarizer axis lays in the plane of incident and reflection beams of the black glass, and the angle of the incident beam on the surface of the black glass plate is the Brewster's angle (for this black glass, $n$=1.51, so $i_B \approx 57^o$);

2) Analyze linear polarized light

   Let sodium light beam sequentially pass two polarizers, rotate one polarizer, observe light intensity change with the variation of angle, and qualitatively demonstrate Malus's law.

3) Analyze elliptical polarized beam:

   Use the He-Ne laser as light source, insert the ¼ λ wave plate between two orthogonal polarizers with known axis directions (axis direction can be determined in Step 1), let the axis of the ¼ λ wave plate at an arbitrary angle, rotate the analyzer in a full turn (360°), the transmitted light will present dark and bright twice alternatively (use a white screen to receive the transmitted light), at the dark position, the transmission direction of the analyzer is the direction of the short axis of the ellipse.

4) Analyze circularly polarized light and determine the axis of ¼ λ wave plate

   Use the He-Ne laser as light source, insert the ¼ λ wave plate between two orthogonal polarizers with known axis directions, when the angle between polarizer and ¼ λ wave plate is 45° or 135°, rotate the analyser and output light intensity doesn't change (use a white screen to receive the transmitted light), therefore the axis of ¼ λ wave plate will be at 45° or 135° with respect to the polarizer axis; the transmitted light from the analyzer is therefore circularly polarized.

5) Demonstrate birefringence phenomenon

   Hold the Iceland crystal (SZ-48) and look into the aperture from the side of large hole. Two bright spots can be observed. This means the light ray entering the small hole on the front side are split into two rays of slightly different paths. This phenomenon demonstrates the crystal is optically anisotropic or is birefringent. Furthermore, illuminate a He-Ne laser beam into the input aperture of the Iceland crystal, the transmitted beam will be split into two beams, rotate the crystal, *o* beam and *e* beam as well as their polarization directions can be determined using a polarizer. Note: since this is a natural crystal of educational grade, there might be some cracks inside, which might blur the laser beams.

## 3.23 Recording and Reconstructing Holograms

**Objective:**

Understand the principle of holography; learn to record and reconstruct holograms

**Experimental Setup**

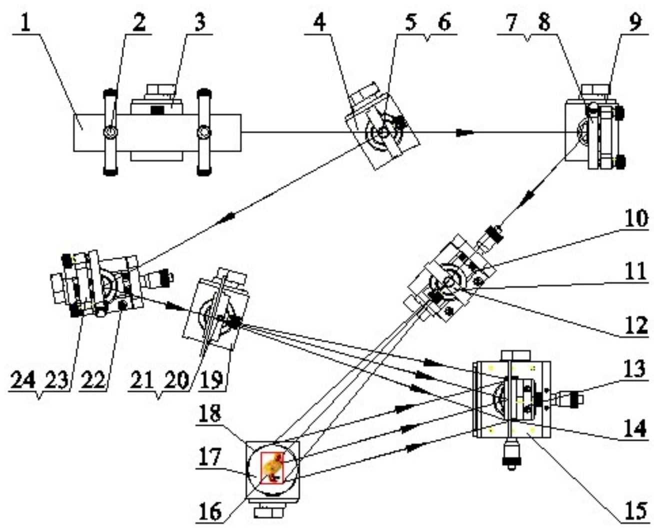


Figure 23-1 Schematic of experimental setup

| | |
|---|---|
| 1: He-Ne Laser (LLL-2) | 11: Beam Expander Lens $L_1$ ($f'$ = 4.5 mm) |
| 2: Laser Holder (SZ-42) | 13: Plate Holder (SZ-12) |
| 3,9,18: Magnetic Base (SZ-04) | 14: Holographic Plate (white plate for initial setup) |
| 4,19: Z-adjustable Stage (SZ-03) | 15: Three-axis Stage (SZ-01) |
| 5: Beam Splitter (7:3) | 16: Small Object |
| 6,12: Lens Holder (SZ-08) | 17: Sample Stage (SZ-20) |
| 7,24: Two-Axis Mirror Holder (SZ-07) | 20: Beam Expander Lens $L_2$ ($f'$ = 6.2 mm) |
| 8: Flat Mirror $M_1$ | 21: Rotatory Lens Holder (SZ-06A) |
| 10,22: Two-Axis Stage (SZ-02) | 23: Flat Mirror $M_2$ |

**Principle**

Light is a transverse electromagnetic wave, so a ray of monochromatic light can be written as

$$x = A\cos(\omega t + \varphi - \frac{2\pi}{\lambda} r) \tag{23-1}$$

where $A$ is the amplitude, $\omega$ is the circular frequency, $\lambda$ is the wavelength, and $\varphi$ is the initial phase.

Generally speaking, a camera can only record the amplitude of the light reflected from an object. So the photo taken by a camera is a planar picture. By contrast, holography can record both the phase and amplitude of the light, thus the image is three-dimensional. Even if a hologram is broken or cut up, each small portion still contains the information of the whole object.

There are two steps in making a hologram. The first step is to record all the information of the light reflected from the object on a holographic plate. The second step is to illuminate the hologram and reconstruct the light wave reflected by the object.

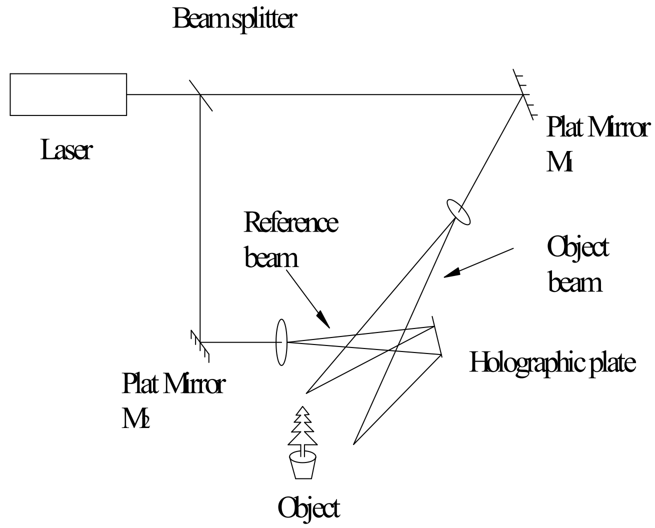


Figure 23-2 Schematic of hologram recording

In fact, holography is a process of interference. As shown in Figure 23-2, a laser beam is split into two beams: one beam, called the reference beam, is directed toward a holographic plate; another beam, called the object beam, is reflected off an object. The object beam contains such information as location, size, shape and texture of the object. Then the two beams produce an interference pattern on the holographic plate, which is recorded in the light sensitive emulsion. As a result, the holograms of the object are obtained. To reconstruct a hologram, a laser beam is used to illuminate on the holographic plate at the same direction as the reference beam. Then the three-dimensional image of the object can be observed.

**Experimental Procedure:**

Note: The hologram recording experiment is recommended to be carried out on a vibration isolated optical table.

1) Refer to Figure 23-1, align all components in same height, let the primary plane of the system parallel to the table, remove $L_1$ and $L_2$ from optical path at this moment;
2) Set approximately equal optical path length for object beam and reference beam, and let their intersection angle about 30° to 40°; let the object close to the holographic plate;
3) Adjust $M_1$, let object beam illuminate on the central portion of the object;
4) Adjust $M_2$, let reference beam illuminate on the central portion of the holographic plate (use a white plate or a paper plate of a similar size for setting up);

5) Insert $L_1$ and $L_2$ back to the optical path, adjust them so that the object beam and reference beam are still at their original centers.
6) Move $L_2$ back and forth to change the illuminating intensity of the reference beam on the white plate; let the intensity ratio between reference beam and object beam about 5:1 to 10:1;
7) Fix all components, turn off indoors light, replace the white plate with a holographic plate and expose the holographic plate with He-Ne laser for 20 to 30 seconds;
8) Develop and fix the hologram;
9) Put back the hologram at its original location, remove object and block object beam, observe the reconstructed object.