Lab 2: Spectrophotometry

Background

Because light behaves macroscopically as a wave (when averaged over millions and millions of photons), it diffracts when encountering regularly spaced scatterers such as grooves or lines in a diffraction grating. By diffract, we mean that light waves appear to “bend” when encountering obstacles whose size is on the order of the wavelength of the light under consideration. It is perhaps better to think of light from a source as forcing the atoms or molecules of the diffraction centers (grooves, lines, etc.) into vibration, whereupon they re-radiate the original light in many directions. If the path length from successive diffraction centers to an observation point is an integer multiple of the wavelength, constructive and destructive interference will occur and bright and dark diffraction patterns will be observed. The spacing between bright parts of the pattern will depend upon the wavelength of the light and so, for example, longer wavelength light will appear to “bend” more when encountering a diffraction grating. By measuring how light from a particular source is bent upon passing through a diffraction grating, one can learn interesting things about the source. This branch of science is called spectrometry.

Imaging Slit

The imaging slit controls how much light goes into the system and strongly influences the spectral resolution of the system. Other factors that affect spectral resolution are the size of the pixels on the imaging sensor and the groove distance of the diffraction grating.

Diffraction Grating

Diffraction gratings are made by scribing closely spaced grooves on glass or some other substrate. The phenomenon of diffraction is one of many manifestations of interference in physics. The incoming beam hits the grooves and scatters in all directions. However, because the initial, non-scattered, wavefront had a common phase, the scattered light will interfere with itself in such a way as to produce maxima and minima as a function of angle (usually measured from the perpendicular to the exit face of the grating.)
Many text books contain the theory of the diffraction grating. The basic result is that maxima in the diffraction pattern are found for angles satisfying the relationship:

$$D \sin \theta = n \lambda$$

(Where “D” is the spacing between grooves, “$\theta$” is the angle between the perpendicular and the diffracted beam, “$\lambda$” is the wavelength and $n$ is the order of the diffraction where $n = 0, 1, 2...$)

Light is typically not monochromatic. There will therefore be an angle which gives a maximum (i.e. a bright image of the slit which we will call a “line”) for each wavelength present in the spectrum of the light source. This means that there will be a characteristic set of lines. Further, this set will repeat as the angle “$\theta$” increases because the phase relationship for a maximum repeats for each increment of $2\pi$. Each repeat is called a “diffraction.”

**In this lab, you will:**

1. Understand the fundamentals of a spectrometry
2. Assemble and align optical components
3. Build an LED light source using basic soldering techniques
4. Collect data from samples and light sources of interest

You will be divided in to 4 groups. Two groups will build a spectrometer. Two groups will use a spectrophotometer. The groups will then switch stations at the half-way point.

**A. Spectrometer Station**
**Setup**

*Tip 1:* Work with one part at a time; do not clutter your workspace. This will help prevent accidentally knocking thing over and breaking lenses.

*Tip 2:* Align components one axis at a time. For example: matching the distance first, then height, then rotation, etc.

In this station we will be putting together a benchtop spectrometer. Using the spectrometer, we will then measure various light sources:

1. Attach the optical fiber from the *lamp* to the SMA mount.
2. Turn on the lamp.
   a. You may view the incident spot using a viewing card for the purposes of alignment, but do not stare directly into any light source.
3. Position the **ACL2520U** lens until the spot size fills >75% of the lens (the flat side should face the light source).
4. Place another **ACL2520U** lens at a distance such that the resulting beam is roughly collimated (the curved side should face the curved side of the other ACL2520U lens).
5. Place the **LB1471** lens in front of the second ACL2520U lens until you obtain a relatively focused spot.
6. Place the **VA100** variable slit at the focused spot adjust the slit opening until it is roughly 2/3 of your spot diameter.
7. Place the **LB1676** lens approximately 2” in front of the slit.
8. Adjust the position of the **GR25** diffraction grating in front the LB1676 lens until the zero and first order diffraction patterns are visible. See the example below. *Never touch the surface of the diffraction grating with your bare hands. Oil from skin will leave a permanent mark on the surface.*

![](image)

**Data Collection**

1. Using the viewing card, take a note of what happens to the light beam at each step of the optical process.
2. Position the camera to capture images of the spectra displayed on the viewing screen.
   a. Be sure the 0th and 1st order diffracted light is in the camera field of view.
   b. Once you pick a camera position, tape it down and do not move it.
   c. Place the black cloth over your setup to block out the room light.
3. Save a picture of the spectra on the viewing screen resulting from the broadband lamp.

4. We will measure two lasers for calibration purposes.
   a. Shine the red laser through the spectrometer.
   b. Capture an image of the resulting spectra on the viewing screen.
   c. Repeat this step for the green laser.

5. Capture the spectrum for the **white LED**

**Clean-up**

1. Disassemble and return all components to how it was when you started, and make sure all light sources are off.
2. If there is an open spectrophotometer station, follow the instructions for that activity.
B. Spectrophotometer Station

![Diagram of circuit with LED, resistor, and DC voltage source]

**Setup**

*Tip 1:* Always follow safe soldering practices. Never touch the heating elements of the soldering iron and do not inhale smoke from flux.

*Tip 2:* Components will heat up when in contact with the soldering iron. Use the tweezers to position components whenever possible.

In this station we will be putting together the circuit for a white LED. We will then measure the spectra of various solutions. Each student will collect their own data. Note that we will be working with soldering tools heated up to ~700°F. If handled incorrectly, you can potentially burn yourself which may result in blistering or even worse. **If you do not wish to use the soldering iron, you may use a pre-made circuit to collect your data.**

1. Gather components from the back and bring them to your station:

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flux core soldering wire</td>
<td>6-10”</td>
</tr>
<tr>
<td>Breadboard</td>
<td>1</td>
</tr>
<tr>
<td>White LED</td>
<td>1</td>
</tr>
<tr>
<td>100 Ω Resistor</td>
<td>1</td>
</tr>
<tr>
<td>Tinned wire</td>
<td>3x of 1 cm segments</td>
</tr>
<tr>
<td>White wire, strip 1 cm from both ends</td>
<td>6-10”</td>
</tr>
<tr>
<td>Black wire, strip 1 cm from both ends</td>
<td>6-10”</td>
</tr>
</tbody>
</table>

2. Put on the safety glasses. The soldering wire we will use in this lab is flux core soldering wire. Fumes and splatter from the flux wire aren’t good for you, so **keep the safety glasses on while soldering.**

3. Turn on the soldering iron station and leave it alone while it heats up.
4. Place the breadboard in the helper hands alligator clips so that the board is relatively flat.
5. Bend the prongs of the **LED** and place them on the breadboard so that there are ~2-3 holes between the LED prongs (see example below). Recall that the **positive** prong of the LED is the longer leg, and the **negative** prong is the shorter leg. See the example below:

![Image of LED on breadboard]

6. Hold the soldering iron by the **black handle** (it should feel warm, but not hot to the touch). Bring the tip of the soldering iron so that it contacts **both** the positive leg and the metallic hole it is placed in.

   a. While the soldering iron is in contact with the LED prong and breadboard hole, briefly touch one end of the soldering wire to add solder. See examples below:

   ![Soldering diagram]

   The amount of solder to add should be similar to the example below:

   ![Soldered breadboard example]
7. Add solder to the negative prong of the LED in the same manner.
8. Add the **100 Ω resistor** to your breadboard. Position it so that it is approximately 2-3 holes from the positive LED leg. See the example below:

![Resistor on Breadboard](image1.png)

9. Now that we have our components on the board, it’s time to connect the circuit. Flip the board around so we can work on the back.
10. Add the **white wire** to your board approximately 3 holes away from the resistor.
11. Add the **black wire** to your board approximately 3 holes away from the negative LED prong.
12. Solder the **tinned wire** segments (use the tweezers to hold them in place) to connect: 1) the white wire to the resistor, 2) the resistor to the positive LED prong, and 3) the negative LED prong to the black wire. See the example below:

![Connectors](image2.png)
13. Touch the ends of the wire to a battery to test your LED circuit. If it lights up, you are good to go.

Data Collection
1. Place your completed LED board into the circuit board clamp by the spectrometer (located at the back of the room).
2. Place the blank “W4” (water) cuvette in front of the spectrometer.
3. Turn on your LED and position it (i.e. angle and distance) so that the spectrometer is not saturating.
4. Using the Window’s Snipping Tool, take a snapshot of the spectrum. See the example below. Make sure you also capture the borders of the window.

![Image of a spectrum]

5. Without changing anything else in your setup except the cuvette, take measurements of the other solutions: N1, M2, and H3.

Clean-up
1. Disconnect the battery from your board and remove it from the clamp. Leave the battery there. If you do not wish to keep your LED board, also leave it there.
2. If there is an open spectrometer station, follow the instructions for that activity.