Spectroscopy

A. Observing Spectra

The goal of this exercise is to learn how to use diffraction gratings and hand-held spectrometers to observe the spectrum of a light bulb, gas tube, or other source of light and measure the wavelengths of light they produce. Visible light is made up of waves that have very short wavelengths. A useful unit in which to measure these tiny wavelengths is the **nanometer**. One nanometer is equal to $10^{-9}$ meters (i.e. one billionth of a meter).

**Diffraction gratings**: You can find out what colors a light source is emitting by observing it with a diffraction grating. Diffraction gratings are similar to prisms: they spread light out into its constituent colors. Practice using the diffraction gratings mounted in slides by observing the following objects. Orient the grating so that the colors appear to the left and right of the object you are observing (not above and below).

**IMPORTANT**: *Always hold the diffraction grating slide by the edges.* Fingerprints on the grating itself will cause damage to the grating. *If the gratings appear dirty or smudged, do not wipe them off (which will ruin the grating).*

(i) **Incandescent bulbs** (wait until overhead lights are turned off)

Incandescent bulbs contain a metal filament that gets very hot and glows when current is made to flow through the filament by turning on the light. The spectrum the hot filament produces is called a “continuous” spectrum, because all the wavelengths of light are present (the spectrum has no breaks).

**Q1**: How many different colors can you see in the spectrum? List them.

**Q2**: Notice that the diffraction grating produces more than one spectrum. Compare the two spectra that appear closest to the source of light, one to the left of the light, and one to the right. Are the two spectra identical? (Are the colors in the same order, left to right, and separated by the same amount) If not, what is different? Which end of the spectrum (blue or red) appears closest to the source of light in each case?

A diffraction grating produces multiple spectra, which can be confusing until you get used to it. The spectrum closest to the light source (one on either side) is called the “first order” spectrum. The next spectrum over (moving away from the light) is called the “second order” spectrum.

**Q3**: Take a close look at the second order spectrum on one side of the light source. How does it compare to the first order spectrum on that side? Is the second order spectrum brighter or fainter? Are the colors in it spread out more or less than in the first order spectrum?
(ii) **Emission-line sources** (gas tubes)

Now try observing the glowing gas tubes through the diffraction grating. Both produce what are called “emission spectra.”

**Q4:** What is different about the spectrum from the gas tubes, as compared to the incandescent bulbs? Describe the appearance of the spectrum (color and shape of what you see).

**Hand-held spectrometers**

(i) **Incandescent bulbs** (wait until overhead lights are off)

**Q5:** At about what wavelength do you see the color yellow? (Use units of nanometers [nm], as marked on spectrometer lower scale.)

(ii) **Fluorescent lights** (overhead lights)

Before going on to Exercise 2, we need to check the “calibration” of the spectrometers. That is, we need to check if the wavelength readings are correct. We can do this using fluorescent lights, as follows. Point the spectrometer slit at one of the fluorescent lights overhead, and observe the spectrum it creates. Notice the pair of green lines (they might look like one fuzzy thick line). Also notice the tick mark on the bottom (nanometer) scale at about 550 nm. (We won't be using the top scale at all.) If your spectrometer is properly calibrated, the green lines will appear on either side of this tick mark.

*If your spectrometer appears not to be properly calibrated, or doesn't seem to be working properly, ask your instructor for assistance!*

**Q6:** About how far apart in nanometers are the two green lines?

**B. Light and colors in Spectra**

Five mini-experiments are described in the following pages. The lab room is set up with three stations, and two additional stations are outside the classroom. Work in groups of 2, each group with one spectrometer and each student with one grating. If necessary, groups of 3 are okay, too. The experiments at the various stations can be performed in any order. When you’ve completed the questions associated with one, find another station that is free, and proceed to answer the questions associated with it.

**Station #1: Wavelengths of visible light**

**Setup:** *Incandescent bulb and overhead projector to provide illumination of scale on hand-held spectrometer.*
To do:  *Aim the slit of the spectrometer at the bulb, and carefully observe the spectrum it creates. You will need to be able to read the bottom scale of the spectrometer (the one in nanometers). Position yourself in such a way that the projector light illuminates the scale.*

**Q1.1:** What kind of spectrum does the incandescent bulb create? (Continuous, emission, or absorption)

Stand close enough to the bulb so it creates a nice, bright spectrum in your spectrometer. Notice which color you see at each end (left or right edge) of the spectrum. Using the scale below the spectrum, read off the wavelength in nanometers (nm) at each end of the spectrum. This will give you the range of wavelengths that are visible to the human eye (the light bulb also emits plenty of infrared radiation, but you can’t see it).

**Q1.2:** Which color is at the left end of the spectrum? What is its wavelength? What color is at the right end of the spectrum? What is its wavelength? Don’t forget units!

**Q1.3:** By carefully examining the spectrum, record the wavelength ranges (in nanometers) corresponding to the colors in Table 1 on the worksheet. The short wavelength side is the smaller number for one color (towards the purple side). The long wavelength side is the larger number (towards red side). Don’t forget to record the units!

**Station #2: Identifying elements using patterns of spectral lines**

Tubes of glowing gas can be used to simulate glowing gas in the galaxy, such as that illuminated by hot, young stars in the nebula M42 (the star-forming region in Orion’s belt). Here we learn how to identify the elements in gases via their spectral lines.

**Setup:** *Two gas tubes mounted in power supplies, poster of spectral features of various elements (with light to illuminate it).*

**To do:** *Use the diffraction gratings to observe the spectrum created by each gas tube. Pay close attention to the colors of each of the “lines”. (Note that in this setup, a “line” is an image of the gas tube at a certain wavelength.) Be sure you are observing only the first order of the spectrum.*

**Q2.1:** What kind of spectra do the tubes of glowing gas create? (Continuous, emission, or absorption)

**Q2.2:** Sketch each of the spectra in the boxes on the worksheet, and label each of the lines with its corresponding color. Be sure you are observing only the first order spectrum, and record only lines that are reasonably bright. Take care to reproduce the spacing of the lines as well as possible.
Now see if you can identify what element each gas tube contains by looking at the poster. The colors on the chart don’t correspond perfectly to what you’ll see by eye (especially in the blue part of the spectrum). Also, lines you see as single may correspond to two closely spaced lines on the chart. Start by focusing on one bright line, and checking which elements are supposed to have that line. Then consider a second bright line. Can you narrow it down further? Keep adding more lines until you’ve narrowed it down to the best possible match.

**Q2.3:** What is the element in gas tube #1? What is the element in gas tube #2?

**Station #3: Identifying elements using wavelengths of spectral lines**

To identify an element correctly from its spectral lines, it’s often not enough to just observe whether there is a line “in the red part of the spectrum,” or “in the green,” or whatever. The terms “red” and “green” (as well as other colors) cover quite large ranges of wavelength! To identify an element with more confidence, you need to measure the wavelengths of the lines it produces more precisely. This is what spectrometers are for.

**Setup:** *Two gas tubes mounted in power supplies, poster of spectral features of various elements (with light to illuminate it).*

**To do:** *Observe each gas tube through the spectrometer.*

**Q3.1:** What kind of spectra do the tubes of glowing gas create? (Continuous, emission, or absorption)

**Q3.2:** Sketch each of the spectra on the worksheet, and label each of the lines with its corresponding color. Record only the reasonably bright lines. Measure the wavelength of at least two of the lines in each spectrum (use nanometers), and label them clearly.

Now see if you can identify what element each gas tube contains by looking at the wall chart (see Station 2 for instructions). Find an element that has lines at (or very close to) the same wavelengths you measured above.

**Q3.3:** What is the element in gas tube #3? What is the element in gas tube #4?
Station #4: Identifying elements in fluorescent lights

Setup: *Fluorescent lights in separate room*

To do: *Point the slit of the hand-held spectrometers at a bright part of one of the fluorescent lights. Carefully observe the spectrum the light produces.*

Q4.1: What kinds of spectra do the fluorescent light create? (Continuous, emission, or absorption)

Q4.2: What spectral lines can you identify from the light? List all the reasonably bright lines you can see, record the color, and measure their wavelengths.

Q4.3: The overall color produced by fluorescent lights is not quite the same as natural lighting (i.e. sunlight). Why do you think this is so?

Q4.4: Can you think of any way a light source that produces only emission lines could create an effect more closely resembling that of natural sunlight? How would it work?

Station #5: Identifying elements in the Sun (outside)

**IMPORTANT: Never look directly at the Sun, and never point the spectrometer at the Sun!**

Setup: *Sunny day: Find a roof or light-colored wall outside that is reflecting a lot of sunlight. Cloudy day: Find a patch of clouds or fog that is reasonably bright, but far from where the Sun might be.*

To do: *Point the slit of the hand-held spectrometer at the source of reflected light. Carefully examine the resulting spectrum. The brighter the reflection, the easier it will be to see faint features in the spectrum. (Remember, NEVER point at the Sun itself!)*

Q5.1: What kind of spectrum does the Sun create? (Continuous, emission, or absorption)

Q5.2: What spectral lines can you identify from the light? List up to five lines (but only ones you’re sure you really see), and label the color of the spectrum they appear in. Also, use the scale provided in the hand-held spectroscope to estimate the wavelength at which each line appears.
Spectroscopy Worksheet

Table 1: Wavelength ranges of colors

<table>
<thead>
<tr>
<th>Color</th>
<th>Shortest Wavelength</th>
<th>Longest Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Violet</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q2.2: Spectrum of gas tube #1:

- Red
- Blue

Q2.2: Spectrum of gas tube #2:

- Red
- Blue

Q3.2: Label each spectrum with wavelengths of at least two lines (in nm)

Q3.2: Spectrum of gas tube #3:

- Red
- Blue

Q3.2: Spectrum of gas tube #4:

- Red
- Blue