Optical Emission Spectroscopy

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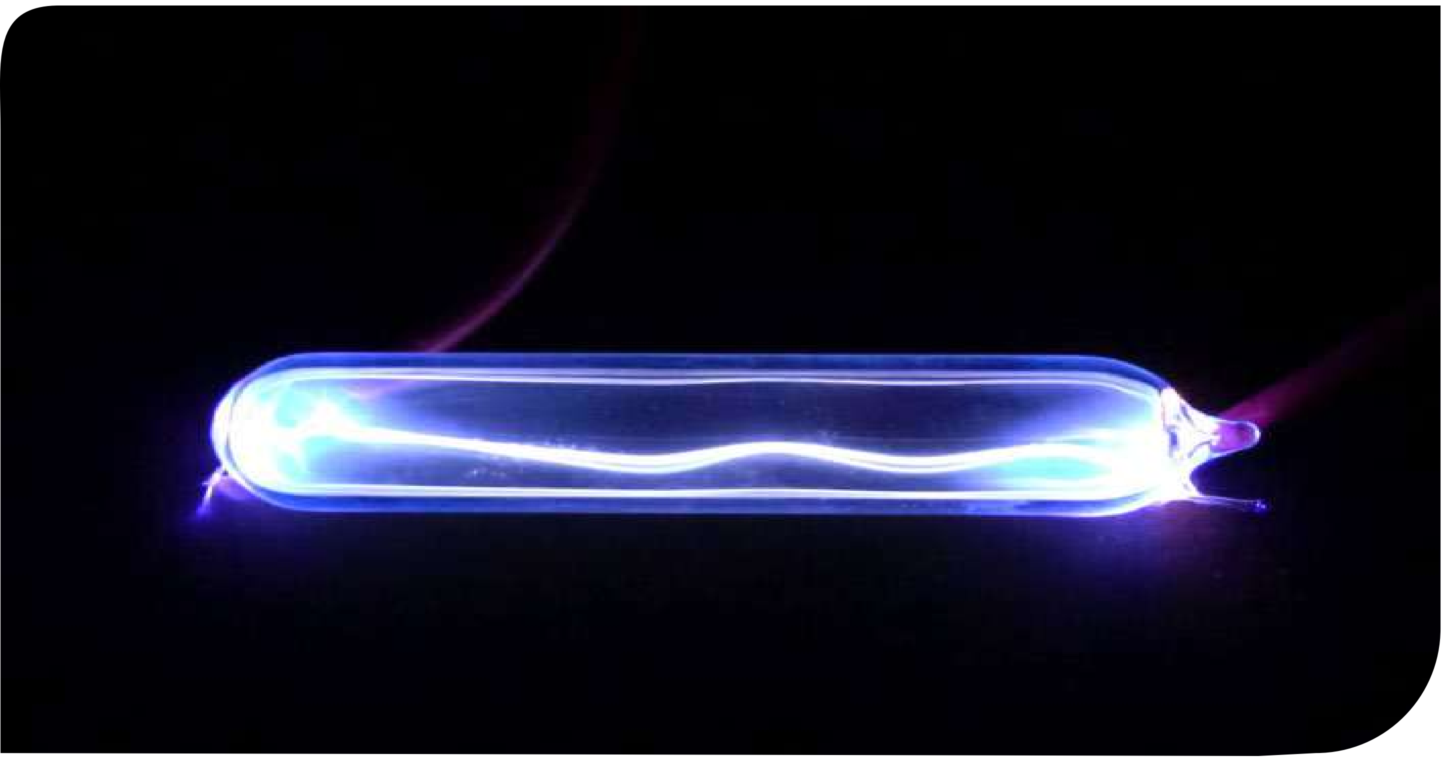


Optical Emission Spectroscopy

Investigate the emission spectrum of a gas discharge source using a diffraction grating, lasers of known wavelengths, and a spectrometer. Students will observe multiple diffraction orders, use the laser wavelengths as reference points to estimate the wavelengths of the gas's emission lines, and compare their visual and image-based results with the spectrum measured by the spectrometer.

INTRODUCTION

Learning Goals

You just graduated and the company you are working at makes sources that require spectral calibration and you need to learn exactly what wavelengths are emitted. Your job is to configure and calibrate an optical wavemeter, a device that precisely measures the wavelengths emitted by an optical source.

For more on spectroscopy – visit StellarNet's learning center :
https://www.stellarnet.us/spectrometers/uv-vis-spectrometers/learning-center/

Gas Discharge Lamps

A gas discharge source produces light by applying a voltage across two electrodes inside a sealed tube containing a gas. The electric field accelerates free electrons through the gas, causing them to collide with gas atoms and transfer energy to them. These collisions excite the atoms' electrons to higher energy levels.

When the excited electrons return to lower energy levels, they release energy as photons at specific wavelengths. Together, these emitted wavelengths produce the characteristic color associated with the gas—for example, the familiar reddish-orange glow of neon. When examined with a diffraction grating or spectrometer, this color separates into a series of distinct emission lines. Because each element has a unique set of energy levels, its emission spectrum acts like a spectral fingerprint that can be used to identify the gas.

Wavemeters and Diffraction Gratings

In industry, devices called wavemeters measure the exact wavelengths emitted by optical sources. In this lab, you will construct the essential components of a basic wavemeter and use your setup to measure the available optical sources. The heart of a wavemeter is a diffraction grating. This optical component is a glass or plastic window that is ruled or embossed with microscopic lines that disperse broadband light into its constituent colors.

When light passes through the grating, it is spread into its spectrum via the phenomenon of diffraction, revealing all colors that comprise the source light.

The parameters of the diffraction process are determined by the diffraction equation:

$$d \times \sin\theta = m \times \lambda$$

A straightforward measurement setup is described in the following section. When using this setup, it is useful to make the small-angle approximation, so the diffraction formula reduces this equation for easier calculations:

$$d \times \frac{y}{L} = m \times \lambda$$

Where

d ≡ grating spacing
θ ≡ angle to which the wavelength is diffracted
y ≡ spacing along screen from central (zeroth) order to measured spectral line or region
L ≡ distance from grating to source
m ≡ order of diffraction (count from the central order)
λ ≡ wavelength located at screen position y

PRELAB QUESTIONS

1. How does applying a voltage across the electrodes of a gas discharge tube cause the gas to emit light?

2. Why does each gas produce a unique pattern of emission wavelengths?

3. does applying a voltage across the electrodes of a gas discharge tube cause the gas to emit light?

4. Why does each gas produce a unique pattern of emission wavelengths?

5. What happens when light from a gas discharge source passes through a diffraction grating?

6. How do the measurements obtained with a diffraction grating compare with those collected using a spectrometer?

PROCEDURE

Materials and Equipment

- ✓ One optical breadboard
- ✓ One fiber-coupled spectrometer with input fiber, cosine receptor, calibration, computer, and software
- ✓ Your camera
- ✓ One linear, one-dimensional diffraction grating
- ✓ One plasma source
- ✓ One (or more) low-power lasers of a known wavelength
- ✓ One StellarNet fiber-coupled spectrometer with input fiber, computer, and software.

Don't forget to document the manufacturer, model, and serial numbers of all hardware used.

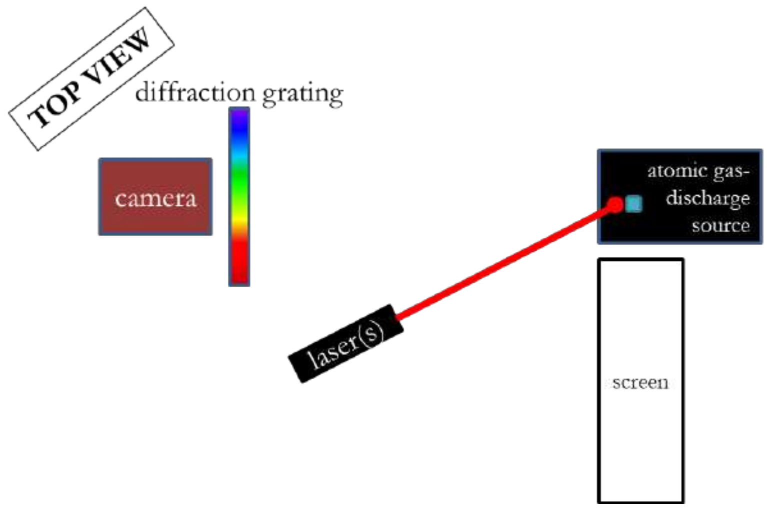
System Configuration

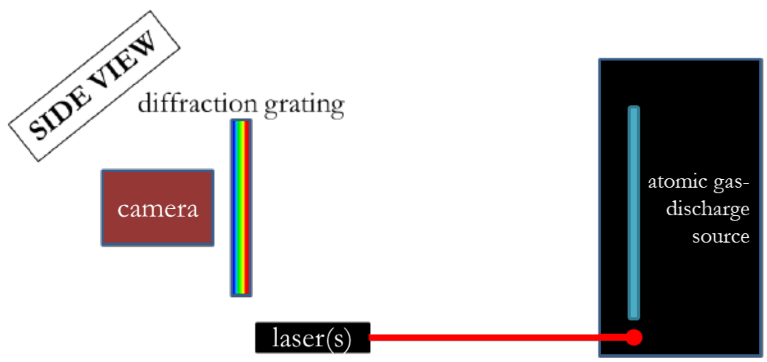
Place the plasma source at one end of the optical bench, and a transmissive diffraction grating on the other end, so you can view the source through the grating, as if it is a window.

Position a screen adjacent to and in the same plane as the source.

Orient the grating to diffract light in a horizontal direction.

Direct one or more lasers onto the plasma source housing, aligning the laser spot(s) exactly below the line of the gas source tube. This creates a scattered spot of laser light from where the laser strikes the plasma source housing.





Experimental Procedure

1. While looking through the transmissive diffraction grating, observe the spread of colors onto the screen from both the plasma source and the diffracted spots of the laser(s). Be sure to look off to the one side at the diffracted orders, not directly back at the source. The direct view is called the zeroth order, and each diffracted order is numbered sequentially to each side (first, second, etc.). Use your eyes as the detector, looking through the grating to see light diffracted from both the plasma source and the scatted laser spot. **Can you view two diffracted orders of the laser?**
2. After you've observed the spectrum, take pictures through the grating to collect data. Be careful to orient the grooves of the diffraction grating to be vertical, so the diffracted spectra are horizontal and each color falls on a different column of your camera's pixels. The clocking between the grating's grooves and your camera's pixel columns is important to align.
3. Ensure you capture two diffracted orders of the laser spot(s) in each image. Experiment of various configurations of the plasma source and diffraction grating, change the distance

between them if required. Document and note the changes if any between the different configurations.

4. Observe and document where the diffracted laser spot(s) fall within the diffracted spectrum. Since the lasers wavelengths are written on their packages and datasheets, the image's pixel column on which diffracted spots fall calibrate the wavelength at that location (pixel column). (For instance, if the second diffracted order of a red HeNe beam falls on pixel column 147, then pixel column 147 represents the location of 1265.6-nm light (twice 632.8 nm) for your particular hardware configuration.)
5. Mark and measure the distance along the screen from the zeroth order – the laser spot itself – to the diffracted first orders (the first diffracted laser spot). You will have to work together with your partner to document where the diffracted orders are viewed. Mark and measure the distance to the second and any higher-order laser spots as well.
6. Configure the StellarNet spectrometer as you did in your previous lab and point the detector at the plasma source. Record the measured spectrum (save .SSM file)

DATA ANALYSIS

1. Document your measurement setup with sketches and/or photographs
2. Find the lateral distance to all prominent diffracted orders via your images, measuring their location in pixel columns, using image-processing software.
3. Use the measured data, the known laser wavelength, and the formula above to calculate the grating's spacing d, in units of distance.
4. Using at least two diffracted laser spots, calculate a scale factor that converts diffracted lateral position (pixel column) to known wavelength in [nm]. Each measurement geometry (that is, each image with even a slightly different camera angle or source position) requires a new scale factor.
5. Determine the pixel columns of the prominent diffracted colors of the plasma source.
6. Multiply the pixel-column values for each prominent diffracted color by your scale factor to calculate the wavelengths of the plasma source spectrum.
7. Relate the scale factor to your hardware: which physical parameters determined the scale factor?
8. Compare the spectrum measured by your images to the spectrum measured by the spectrometer. Document how well spectral features aligned.

9. Discuss measurement errors and recommend improvements.

DISCUSSION QUESTIONS

1. How did the appearance of the plasma source differ between the zeroth, first, and second diffraction orders?

2. How did changing the distance or alignment between the source, diffraction grating, and camera affect the spacing, clarity, or position of the observed emission lines?

3. Using the known laser wavelength, how could the laser diffraction spots be used to estimate the wavelengths of the plasma source's emission lines?

4. Compare the emission lines observed through the diffraction grating with the spectrum recorded by the StellarNet spectrometer. Did the same major wavelengths appear in both measurements?

5. What factors may have caused differences between the wavelengths estimated from the photographs and those measured by the spectrometer? Consider alignment, pixel resolution, image distortion, ambient light, and measurement accuracy.

6. Why might some emission lines appear brighter to the eye or camera but have different relative intensities in the spectrometer measurement?

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