Experiment 2: Spectral Lines: Further Understanding the Wave-Like Nature of Light

Purpose

The purpose of this experiment is to explore the wave-like nature of light by:

- Determining and studying the emission spectrum of Mercury via optical spectroscopy;
- Identifying unknown elements via spectral analysis.

Part 1 of this experiment will introduce and familiarize you with the basic ideas of spectral analysis by examining emission spectra of known and unknown elemental gases with a simple digital spectroscope. This introduction is intended to be qualitative and exploratory. In Part 2, you will rigorously and quantitatively analyze spectral lines of known and unknown elemental gases using an analogue spectrometer.

Part 1: Qualitative Spectral Analysis with a Digital Spectroscope

Introduction

Consider a tube of gas; let's say it contains Mercury vapor. Applying a potential difference across the gas tube excites the atoms in the gas; that is, the electrons in these atoms climb to higher energy levels. When the electrons de-excite back down to their original energy levels, they emit photons. The energy of a photon, ΔE, is related to its wavelength via the following equation[4]:

$$\Delta E = \frac{hc}{\lambda},$$

where h is Planck's constant and c is the speed of light in a vacuum.

Since the atoms in a gas exist in a variety of energy states, one observes a range of photons emitted from the gas at various wavelengths. Some electrons will transition between only one energy state and give off a small ΔE, which corresponds to a large λ. That's why violet light has the shortest wavelength of all optical light but has the highest energy!

Light produced by this gas tube can be collimated and directed into a diffraction grating – a series of slits separated from one another by a distance d. The diffraction grating creates an interference pattern – a line – for each wavelength of light produced by the gas. The

[4]Note: If you haven't seen this equation before, take a few moments to consider its incredible implications – *energy is quantized: it is discrete, not continuous!*

collection of these patterns produced is called the *spectrum* of the gas. The patterns/lines themselves are called *spectral lines*.

Experiment

In Part 1 of this lab, we will analyze spectral lines using a digital spectroscope: the *RSpec-Explorer*. The RSpec-Explorer, pictured in the figure below, consists of a video camera with an internal diffraction grating, a stand for the camera, two pieces of black foam board, and a stand for the foam board pieces. You will also need a gas tube light source and power supply for this experiment.

The RSpec-Explorer Digital Spectroscope

Setting Up the Equipment & Installing the Digital Spectroscope Software

1. Gather the following relevant lab equipment. You will need:
   - 1 × Mercury gas tube,
   - 1 × "unknown" gas tube,
   - 1 × gas tube lamp base/power supply)
   - 1 × Rspec-Explorer spectroscopy kit
2. On your computer, open a web browser and

   http://www.fieldtestedsystems.com/GetRex/

   and download the RSpec-Explorer software for your platform. The software works only on Windows & Mac – at least one person in your group should probably have one of these operating systems (if not, please inform the instructor!).
3. Install the RSpec-Explorer software you downloaded.
4. Once installed, plug in the RSpec camera and start the RSpec-Explorer software.

5. Set up the RSpec camera a few feet away (it doesn't have to be a precise distance) from the gas tube lamp and point the camera toward the lamp.

Experimental Procedure: Examining the Mercury Spectrum

1. Insert the Mercury gas tube into the lamp base and plug the power supply into an electrical outlet.

2. In the RSpec-Explorer software window, you will see a camera view. To ensure that the camera being used is the RSpec camera (and not, say, your laptop's built-in webcam), click on the `Live Camera` tab, click `Open` and select `Webcam C110` as your choice of camera. Now you should see the view of the RSpec camera.[5]

3. Turn on the gas tube lamp. You should see spectral lines appear on top of the video feed.[6] Use the orange capture lines, which are superimposed over the video feed and can be dragged, to bracket in the spectral lines appearing on top of the video feed. The software sums up all the pixels between the orange lines and displays their intensity in a graph on the right side of the window.

4. Next, you need to point the camera at the gas tube. You should see a large, prominent peak in the graph; this is the intensity peak of the gas tube. You should also see a line at 0 nm superimposed over the graph. Rotate the camera until the large prominent peak in the graph is lined up with the superimposed line at 0 nm.

5. Now that the camera is properly aligned, look at the graph. You will notice several prominent peaks. These correspond to the spectral lines that are superimposed over the video feed.

6. Click on the `Elements` button in the toolbar. This opens the Elements window. Click the box for `Mercury` and several vertical lines will appear on the graph.

7. Verify that the prominent peaks in your plot correspond to these lines. This is the Mercury emission line spectrum.

Calibrated against ZEISS Mercury arc lamps

Experimental Procedure: Identify Unknown Spectra

1. You will be given a gas tube containing an unknown gas. Repeat steps 1-5 of the "Observe the Mercury Spectrum" section above, replacing the Mercury gas tube with the unknown gas tube you were give. Find its line spectrum.

2. Compare the spectrum with known spectral lines using the `Elements` tool. Note that you will only be given gas tubes containing single-element gases.

[5]Note that the camera automatically adjusts for brightness and contrast.

[6]If you are having trouble seeing the spectral lines, use the pieces of black foam board to give a dark background to the camera view. Dimming the lights in the room may also be helpful.

3. Identify the gas and record your findings.

Pink glow. Very closely aligns with helium.
Gas tube 2

Part 2: Quantitative Spectral Analysis with an Analogue Spectrometer

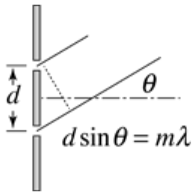
In this part of the lab, you will be performing essentially the same experiment as in Part 1, but you will determine the spectral lines quantitatively via measurement with an analogue spectrometer (rather than simply observing the spectral lines with a simple digital spectroscope).

Introduction

Light produced by an elemental gas tube can be collimated and directed into a diffraction grating – a series of slits separated from one another by a distance d. The diffraction grating creates an interference pattern for each wavelength of light produced by the gas. The collection of these patterns produced is called the element's *(emission) spectrum*.

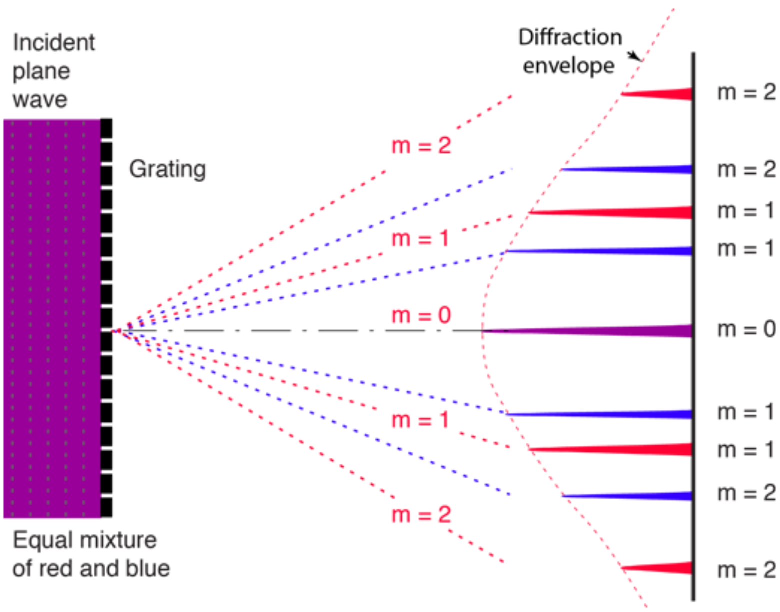
A diffraction grating is the tool of choice for separating the colors in incident light. Diffraction gratings are an immensely useful tool for the separation of spectral lines associated with atomic transitions. It acts as a "super prism", separating the different colors of light much more than the dispersion effect in a prism.

An idealized grating is made up of a set of slits of spacing d, that must be wider than the wavelength of interest to cause diffraction. Assuming a plane wave of monochromatic light of wavelength λ with normal incidence (perpendicular to the grating), each slit in the grating acts as a quasi point-source from which light propagates in all directions (although this is typically limited to a hemisphere). After light interacts with the grating, the diffracted light is composed of the sum of interfering wave components emanating from each slit in the grating. At any given point in space through which diffracted light may pass, the path length to each slit in the grating varies. Since path length varies, generally, so do the phases of the waves at that point from each of the slits. Thus, they add or subtract from each other to create peaks and valleys through additive (constructive) and destructive interference. When the path difference between the light from adjacent slits is equal to half the wavelength, $\lambda/2$, the waves are out of phase, and thus cancel each other to create points of minimum intensity. Similarly, when the path difference is λ, the phases add together and maxima occur.



The maxima occur at angles θ_m, which satisfy the relationship $\frac{d\sin\theta_m}{\lambda} = |m|$, where θ_m is the angle between the diffracted ray and the grating's normal vector, d is the distance from the center of one slit to the center of the adjacent slit, and m is an integer – called the *order* of the spectrum – representing the propagation-mode of interest. Thus, when light is normally incident on the grating, the diffracted light has maxima at angles θ_m given by:

$$d\sin\theta_m = m\lambda \qquad \text{where } m = 0, 1, 2, ..., n.$$



How a Diffraction Grating Splits an Incident Light Wave

The illustration in the above figure is qualitative and primarily intended to show the clear separation of the wavelengths of light. There are multiple orders of the peaks (labeled by m) associated with the interference of light through the multiple slits of the grating. The intensities of these peaks are affected by the diffraction envelope which is determined by the width of the single slits making up the grating. The overall grating intensity is given by the product of the intensity expressions for interference and diffraction. The relative widths of the interference and diffraction patterns depends upon the slit separation and the width of the individual slits, so the pattern will vary based upon those values.

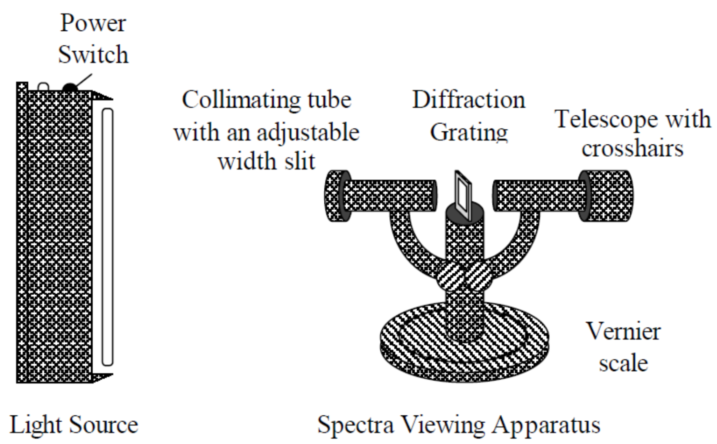
Experiment

First, gather the relevant lab equipment. You will need:

- 1 × Mercury gas tube,
- 1 × "unknown" gas tube,
- 1 × gas tube lamp base/power supply,
- 1 × analogue grating spectrometer,
- 1 × diffraction grating.

Setting Up & Adjusting the Equipment

(1.) The analogue spectrometer consists of three main parts, pictured below: a collimating tube with an adjustable slit, a holder for a diffraction grating, and a telescope with crosshairs.



Analogue Spectrometer Setup

(2.) Rotate the telescope so that the 0 mark of the vernier scale is at 180^o. Lock it in position. Raise the telescope so that it will sight through the center of the diffraction grating and line up the collimating tube with it.

(3.) Adjust the slit on the collimating tube such that it is as narrow as possible, but still open.

(4.) Look through the eyepiece of the telescope (with the apparatus NOT pointed at the gas tube lamp). You should see crosshairs. Focus the eyepiece of the telescope on the crosshairs.

(5.) Focus the telescope on the slit (of the collimating tube) by lining up the crosshairs with the slit.

(6.) Place the diffraction grating in the holder by setting it perpendicular to the collimating tube, and lock it in place. **Do not change the position of the collimator or grating for the rest of the lab!**

(7.) Place the gas tube lamp roughly 10 centimeters away from the slit of the collimating tube and turn on the lamp.

(8.) Unlock the vernier scale and swing the telescope to either side of the center setting until you see the spectrum of the incident light.

(9.) **Do not look directly at the ($m = 0$ order) beam of light for more than a couple of seconds. This light can injure your retina! Do not touch the lamp as it gets extremely hot!**

Experimental Procedure: Measuring the Emission Spectrum of Mercury

To familiarize yourself with the analogue spectrometer, we will use it to find the spectral lines of Mercury. Note that you can record your data in the Spectral Lines Activity which accompanies this lab manual (you can find the activity on the course website).

1. Find the first order ($m = 1$) spectrum. **Record your observations:** Sketch the lines and colors you see. Observe and record (with uncertainties) the diffraction angle both to the right θ_R and left θ_L of the center position, with uncertainties. The average diffraction angle θ is one half the difference between corresponding left and right hand readings:
$$\theta \pm \delta\theta$$
where $\theta = \frac{1}{2}(\theta_R - \theta_L)$, and $\delta\theta = \delta\theta_L + \delta\theta_R$, where each $\delta\theta_L$ and $\delta\theta_R$ are simply Type-B uncertainty estimates associated with each θ_L and θ_R, respectively.

2. You might observe some lines at second ($m = 2$) and higher orders. In these cases, you can – and should – obtain two or more angles for a particular line. **Record your observations** (repeating step 1) for any higher order spectra you see.

3. **Record your observations:** Using the equation $d \sin\theta_m = m\lambda$, calculate and record the wavelength (with uncertainty),
$$\lambda \pm \delta\lambda$$
for each spectral line.

4. If you found any second- or higher-order spectral lines, then you will have two or more calculations for the wavelength of a particular line. This improves the precision of your measurement. Calculate and record the average value for the wavelength of each line that you observe at higher orders: $\bar{\lambda} \pm \delta\bar{\lambda}$.

5. If you haven't already, answer the relevant questions in the Activity which accompanies this lab manual.

Experimental Procedure: Identifying an Unknown Element

Now we will use our understanding of the analogue spectrometer to identify an unknown element by measuring its spectrum.

1. Replace the mercury gas tube in your lamp (after allowing it to cool) with the "unknown" gas tube you were given.

2. Repeat the above steps in the "Measuring the Emission Spectrum of Mercury" section using the unknown gas tube.

3. Identify the unknown element by comparing your wavelength measurements for each spectral line with those in the NIST Atomic Spectra Database:
   `http://physics.nist.gov/PhysRefData/ASD/lines_form.html`.

   Since the database can be somewhat difficult to navigate, you can use the Spectrum Chart in the classroom as well as a digital spectrometer (which we used in Part 1 last week) to help you determine the unknown element, but you must still verify your conclusion by checking against the NIST database.

4. If you haven't already, answer the relevant questions in the Activity which accompanies this lab manual.

Experiment Activity 2: Spectral Lines: Further Understanding the Wave-Like Nature of Light

Part 1: Qualitative Spectral Analysis with a Digital Spectrometer

Problem 1. Identifying an Unknown Element Qualitatively

In Part 1 of the lab, you were asked to use a digital spectroscope to identify an unknown gas. What element did you find was contained in the gas tube you examined?

Helium

Part 2: Quantitative Spectral Analysis with an Analogue Spectrometer

Problem 2. Understanding the Experimental Setup: Mercury Gas

Consider and answer the following questions:

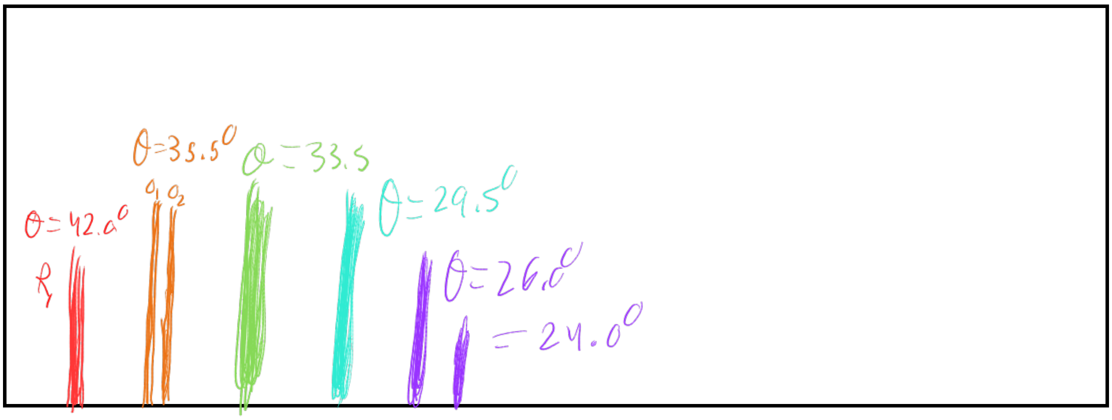
(a.) Printed on the diffraction grating, you will find the number of *lines/mm* the grating contains. Use this information to determine the separation distance between the slits of the grating.

1000 lines/mm, so $d = \frac{1}{1000} mm = 1 \mu m$

(b.) What is the role of the adjustable slit? Why is it adjusted as narrowly as possible?

The adjustable slit limits the range of incoming light, so that we only analyze the spectrum of the gas.

(c.) With the mercury gas tube in place in the lamp base/power supply, observe the spectral lines with your analogue grating spectrometer. In the box below, sketch the lines and colors you see.



(d.) What color is the emission from the mercury lamp? Is it what you would have expected from the combination of colors of the individual lines that you observed?

Problem 3. Finding $\delta\lambda$

Derive an expression for the uncertainty in the wavelength, $\delta\lambda$, that you get from computing λ from your measured values of θ_m using the equation $d \sin\theta_m = m\lambda$. (Remember your rules for uncertainty propagation.) Note that $\frac{d \sin\theta}{d\theta} = \cos\theta$ only if θ is expressed in radians!

$$\lambda = \frac{d \sin\theta_m}{m}, \quad \delta\theta = 1^\circ$$

$$\delta\lambda = \sqrt{\left(\frac{\partial\lambda}{\partial\theta}\right)^2 (\delta\theta)^2}$$

$$\frac{\partial\lambda}{\partial\theta} = \frac{d}{m}\cos\theta_m$$

$$\delta\lambda = \sqrt{\frac{d^2}{m^2}\cos^2(\theta_m)\,\delta\theta^2}$$

$$= \frac{d}{m}\cos(\theta_m)\,\delta\theta_m$$

Problem 4. **Measuring the Emission Spectrum of Mercury: Data Collection**

Record your observations/measurements of the $m = 1$ mercury spectrum here (Don't forget units!): $\delta\theta_R = \delta\theta_L = 2\sqrt{\theta_B^2} = 1^\circ$, $\delta\theta_1 = \frac{\delta\theta_L + \delta\theta_R}{2} = 1^\circ$

Spectral Line Color	$\theta_R \pm \delta\theta_R$	$\theta_L \pm \delta\theta_L$	$\theta_1 \pm \delta\theta_1$	$\lambda_1 \pm \delta\lambda_1$ (m)
Red 1	$139.1^\circ \pm 0.5^\circ$	$221.3^\circ \pm 0.5^\circ$	$41.1^\circ \pm 1$	$(6.57 \pm 0.1) \times 10^{-7}$
Orange 1	$145.0^\circ \pm 0.5^\circ$	$215.5^\circ \pm 0.5^\circ$	$35.3^\circ \pm 1$	$(5.78 \pm 0.1) \times 10^{-7}$
Orange 2	$145.0^\circ \pm 0.5^\circ$	$215.5^\circ \pm 0.5^\circ$	$35.3^\circ \pm 1$	$(5.78 \pm 0.1) \times 10^{-7}$
Green 1	$147.2^\circ \pm 0.5^\circ$	$213.5^\circ \pm 0.5^\circ$	$33.2^\circ \pm 1$	$(5.49 \pm 0.1) \times 10^{-7}$
Cyan 1	$151.1^\circ \pm 0.5^\circ$	$209.5^\circ \pm 0.5^\circ$	29.2 ± 1	$(4.88 \pm 0.2) \times 10^{-7}$
Violet 1	$154.5^\circ \pm 0.5^\circ$	$206.0^\circ \pm 0.5^\circ$	25.7 ± 1	$(4.34 \pm 0.2) \times 10^{-7}$
Purple	$156.0^\circ \pm 0.5^\circ$	$204.0^\circ \pm 0.5^\circ$	24.0 ± 1	$(4.07 \pm 0.2) \times 10^{-7}$

distinct visually, but not measured by instrument

Did you find any second or higher order spectral lines? If so, record those observations/measurements here: None found.

m	Spectral Line Color	$\theta_R \pm \delta\theta_R$	$\theta_L \pm \delta\theta_L$	$\theta_m \pm \delta\theta_m$	$\lambda_m \pm \delta\lambda_m$

If you observed $m = 2$ and/or higher-order spectral lines, combine all corresponding ($m = 1$ and all $m \geq 2$) wavelengths and report the combined wavelengths for each spectral line:

Spectral Line Color	$\lambda \pm \delta\lambda$

Problem 5. Comparing Mercury Spectral Lines With Well Known Values

Given the data you recorded in the previous problem, compare your wavelength measurements for each spectral line with those in the NIST Atomic Spectra Database, which you can find at http://physics.nist.gov/PhysRefData/ASD/lines_form.html. You will have to search the database and find the relevant sets of wavelengths, using your own measurements as a guide.

Do your values agree with values in the NIST database? Check by computing the discrepancy and fractional/percent error between the relevant NIST wavelength values and your measured wavelength values. *Don't simply answer "yes" or "no": show your calculations which check agreement!*

Enough space should be given in the table below to examine several prospective NIST wavelength values that may match your own. Show all work and clearly indicate those you think are the correct matches for each spectral line color. (If you still need more room for calculations, make them on a separate piece of paper and attach it to your submission.)

Pro Tip: The NIST database contains an overwhelmingly large amount of spectral line data. So, limit your database search to wavelengths in the visible range of the electromagnetic spectrum (approximately 380 *nm* to 700 *nm*).

A= relative intensity

Your Wavelengths (Nanometers)	NIST Wavelengths (nanometers)	Agreement? (Show Work to Justify!)
407 ± 2	407.78 ± 0.0001 nm	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 0.78 < 2.0001$ ✓ This agrees, with percent error 0.19%.
434 ± 2	434.75 ± 0.0001 nm	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 0.75 < 2.0001$ ✓ Percent error 0.17% ∴ agrees
488 ± 2	488.03 ± 0.0005	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 0.03 < 2.0005$, agrees ✓ percent error 0.006%.
549 ± 1	546.07 ± 0.0001	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 3.07 \not< 2.0001$, disagrees. Percent error 0.53%. ✗
576 ± 1	576.96 ± 0.0001	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 0.96 < 1.0001$, agrees. Percent error 0.17%. ✓
657 ± 1	658.43 ± 0.0001 A=10	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 1.43 \not< 1.001$, disagrees. Percent error 0.22%. ✗

Problem 6. Measuring the Emission Spectrum of an Unknown Gas: Data Collection

Record your observations/measurements of the $m = 1$ unknown gas spectrum here:

Visually distinct

Spectral Line Color	$\theta_R \pm \delta\theta_R$	$\theta_L \pm \delta\theta_L$	$\theta_1 \pm \delta\theta_1$	$\lambda_1 \pm \delta\lambda_1$
Red	$135.0^0 \pm 0.5^0$	$225.0^0 \pm 0.5^0$	45.0 ± 1	$(7.07 \pm 0.1) \times 10^{-7}$
Scarlet	$138.0^0 \pm 0.5^0$	$222.0^0 \pm 0.5^0$	42.0 ± 1	$(6.69 \pm 0.1) \times 10^{-7}$
Orange	$144.2^0 \pm 0.5^0$	$216.3^0 \pm 0.5^0$	36.1 ± 1	$(5.89 \pm 0.1) \times 10^{-7}$
Cyan	$150.0^0 \pm 0.5^0$	$210.5^0 \pm 0.5^0$	30.3 ± 1	$(5.05 \pm 0.2) \times 10^{-7}$
cyan 2	$150.2^0 \pm 0.5^0$	$210.5^0 \pm 0.5^0$	30.2 ± 1	$(5.03 \pm 0.2) \times 10^{-7}$
light blue	$151.0^0 \pm 0.5^0$	$209.7^0 \pm 0.5^0$	29.4 ± 1	$(4.91 \pm 0.2) \times 10^{-7}$
Prussian blue	$152.0^0 \pm 0.5^0$	$208.2^0 \pm 0.5^0$	28.1 ± 1	$(4.71 \pm 0.2) \times 10^{-7}$
Violet 1	$153.9^0 \pm 0.5^0$	$207.0^0 \pm 0.5^0$	26.6 ± 1	$(4.48 \pm 0.2) \times 10^{-7}$
Violet 2	$154.1^0 \pm 0.5^0$	206.3 ± 0.5^0	26.1 ± 1	$(4.40 \pm 0.2) \times 10^{-7}$

Did you find any second or higher order spectral lines? If so, record those observations/measurements here: None found.

m	Spectral Line Color	$\theta_R \pm \delta\theta_R$	$\theta_L \pm \delta\theta_L$	$\theta_m \pm \delta\theta_m$	$\lambda_m \pm \delta\lambda_m$
				5^0	

If you observed $m = 2$ and/or higher-order spectral lines, combine all corresponding ($m = 1$ and all $m \geq 2$) wavelengths and report the combined wavelengths for each spectral line:

Spectral Line Color	$\lambda \pm \delta\lambda$

Problem 7. Identifying an Unknown Element Quantitatively

Using the data you recorded in the previous problem, identify the unknown elemental gas by comparing your wavelength measurements for each spectral line with those in the NIST Atomic Spectra Database (http://physics.nist.gov/PhysRefData/ASD/lines_form.html). This should be done similarly to Problem 5, except now you do not know ahead of time what the gas in the tube is composed of. You will therefore have to compare your results with several possible matches in the NIST database. Use the table below (and partition it as needed by possible element matches or however you see fit) to help identify the unknown gas you were given.

Once you have come to a conclusion, state the name of the element you identified in the box below, and explain how you came to that conclusion.

Pro Tip: Consider, for example, the following to help you narrow down and guide your database search:

- What color light is emitted?
- How does the spectrum compare to spectra displayed on the Spectrum Chart provided in the classroom?
- What other tools can you use to help identify the gas? (the RSpec, perhaps?)

Your Wavelengths (NM)	NIST Wavelengths	Agreement? (Show Work to Justify!)
440 ± 2	$438.79 \pm 1 \cdot 10^{-6}$	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 1.21 < 2.0000006$ ✓ percent error 0.28 %. agrees
448 ± 2	447.15 ± 0.0002	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 0.85 < 2.0002$ ✓ Percent error: 0.19 %. agrees
471 ± 2	471.31 ± 0.00006	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 0.31 < 2.00006$ ✓ Percent error: 0.07 %. agrees
491 ± 2	492.19 ± 0.00005	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 1.19 < 2.00005$ ✓ Percent error: 0.24 %. agrees
503 ± 2	501.57 ± 0.00003	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow 1.43 < 2.00003$ ✓ Percent error: 0.28 %.

Your Wavelengths	NIST Wavelengths	Agreement? (Show Work to Justify!)
505 ± 2	504.78 ± 0.001	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow$ 0.22 < 2.001 √ Percent error: 0.04 % agrees
589 ± 1	587.56 ± 0.001	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow$ 1.44 $\not<$ 1.001 Percent Error: 0.24 % X disagrees
669 ± 1	667.82 ± 0.001	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert \Rightarrow$ 1.18 $\not<$ 1.001 √ Percent Error: 0.18 % agrees
707 ± 1	706.57 ± 0.01	$\Delta\lambda < \lvert\delta\lambda_1 + \delta\lambda_2\rvert$ 0.43 < 1.01 √ Percent error: 0.06 % agrees

Design Considerations

Problem 8. Improving the Experiment

(a.) Consider the RSpec Explorer software you used in Part 1. Suppose you are a software developer working on improving this software for academic/teaching or for experimental/research purposes. What other useful features could you add to the software to make it easier to identify unknown gases from their emission spectra? (Assume you have any/all relevant computational skills to implement whatever helpful features you want to add.)

See Semi-Report

(b.) How might you change the experimental setup or environment in Part 2 to help better identify the unknown gas?

See Semi-Report

Semi-Report

This part of the lab activity is designed to encourage you to think about how parts of a formal lab report for this experiment might be written. For all of the following questions, suppose (i.e., pretend) you are writing a formal lab. **All questions in this "semi-report" section should be answered in a text file (or via LaTeX) and submitted electronically on the course website.**

Use the appendix ***Writing Scientific Lab Reports*** *as a guide.*

Problem 9. Historical Notes

In your own words, discuss the historical aspects of the experiment from Part 2, as if you were writing a `Historical Background` section of a report or scientific article.

Some things worth considering:

- What were the historical and scientific consequences of the original spectral lines experiments?
- Who first studied spectral lines?
- How has physics changed because of this then-newfound understanding of spectral lines?

(It will be helpful to refer to your Modern Physics textbook, or other resources, to help you write a few paragraphs to answer these questions. This may require a little bit of research.)

Problem 10. Theoretical Background

In your own words, discuss the theoretical background of the experiment from Part 2, as if you were writing a `Theoretical Background` section of a report or scientific article.

Consider answering and discussing the following questions:

(a.) How is light emitted by the gas tube lamp? What physical mechanisms come into play here?

(b.) How does a diffraction grating separate incident light waves into spectra?

Answering these questions may include the use of (and/or derivation of) equations.