Spectroscopy Using a Monochromator

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A hydrogen lamp was placed in front of the slit to a scanning spectrometer, peaks of the Balmer series were determined to be 434.01 ± 0.08 nm, a difference of $0.5\,\sigma_{H434}$ from the NIST reported value of 434.0462 nm; 486.03 ± 0.08 nm, a difference of $1.3\,\sigma_{H486}$ from the NIST reported value of 486.13615 nm; and 656.14 ± 0.08 nm, a difference of $1.8\,\sigma_{H656}$ from the NIST reported value of 656.28518 nm. The spectral line at 410 nm was not located. Based on three points, the Rydberg Constant was calculated to $(1.097 \pm 0.08) \times 10^7\,\mathrm{m}^{-1}$, at the given significant figures a match with the value reported by NIST. Light from a sodium lamp was then analyzed. Two prominent peaks were located: the first was (588.97 ± 0.08) nm, a difference of $12.8\sigma_{Na588}$ from the NIST reported value of 589.9950 nm and the second at (589.57 ± 0.08) nm, a difference of $0.3\sigma_{Na589}$ from the NIST reported value of 589.5924 nm. The distance between the two measured wavelengths is (0.60 ± 0.08) nm, a difference of $< 0.1\sigma_{Na}$ from the value reported in a previous experiment. Lastly a mercury lamp was analyzed and several peaks were identified. The first set of peaks were (312.52 ± 0.08) nm and (313.13 ± 0.08) nm, differences of $0.6\sigma_{Hg313}$ from the NIST reported values of 312.567 nm, 313.155 nm, and 313.184 nm, respectively. The second set of peaks were (365.00 ± 0.08) nm, (365.48 ± 0.08) nm, and (366.31 ± 0.08) nm, differences of $0.2\sigma_{Hg365a}$, $0.1\sigma_{Hg365b}$, and $0.2\sigma_{Hg365c}$ from the NIST reported values of 365.015 nm, 365.484 nm, and 366.328 nm respectively. The third peak was (404.49 ± 0.08) nm, a difference of $0.2\sigma_{Hg404}$ from the NIST reported value of 404.656 nm. The fourth set of peaks were (433.94 ± 0.08) nm, (434.75 ± 0.08) nm, and (435.68 ± 0.08) nm, differences of $0.2\sigma_{Hg434a}$, $< 0.1\sigma_{Hg434b}$, and $1.9\sigma_{Hg434c}$ from the NIST reported values of 433.9223 nm, 434.7494 nm, and 435.8324 nm respectively. The fifth peak was (546.03 ± 0.08) nm, a difference of $0.6\sigma_{Hg546}$ from the NIST reported value of 546.074 nm. The sixth set of peaks were (576.74 ± 0.08) nm and (578.83 ± 0.08) nm, differences of $2.7\sigma_{Hg576a}$ and $2.9\sigma_{Hg576b}$ from the NIST reported values of 576.9598 nm and 579.0663 nm respectively. The wavelengths of mercury observed in the lamp conforms with mercury I. No mercury II peaks were discerned in the wavelength range inspected.

Supervising Instructor: Thomas Colbert

I. INTRODUCTION

This experiment uses a single-beam spectrometer, where polychromatic light is focused on an entrance slit and dispersed via a reflective grating. The reflective grating is rotated by a micro stepper motor, so that very narrow portions of the wavelength spectrum is focused on an exit slit. At the exit slit individual photons are collected, converted to electrical current and amplified via a photomultiplier, then measured. (see Figure 1, below for a representative diagram).

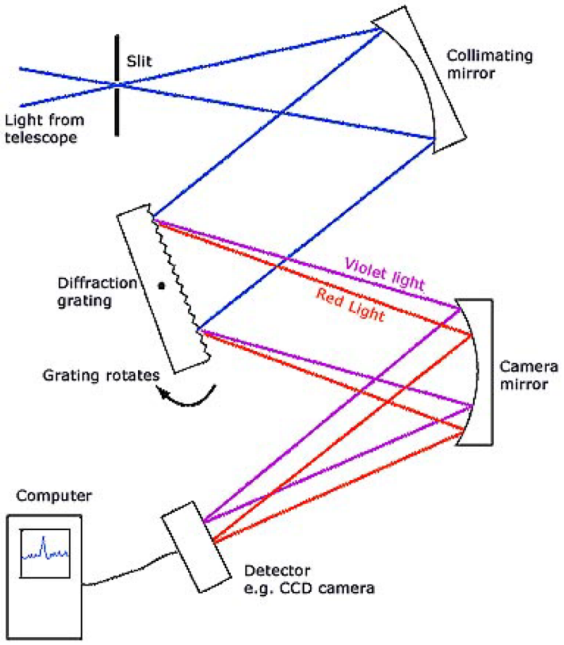

Figure 1: Diagram of Spectrometer. An exit slit with a photomultiplier is used in place of the CCD camera. Source: [7]

In addition to the basic internal design of the spectrometer, some external components are added to enhance the ability to collect data and the precision of the data collected. A convergence lens is used to focus the light source onto the entrance slit. An optical chopper is used with a lock in amplifier to amplify and measure the current produced by the photomultiplier in a manner that filters out untargeted light (see Figure 2, below).

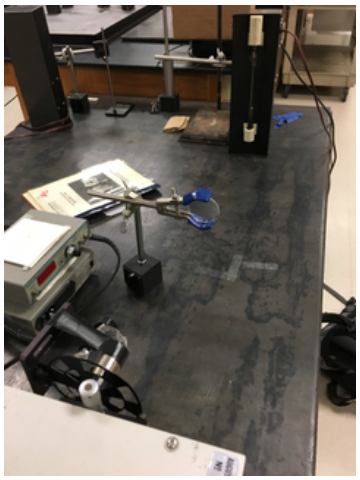

Figure 2: Lens and Optical Chopper.

The spectrometer has capabilities to measure wavelengths in the range of 300 to $600\,\text{nm}$, primarily the visual range of humans. This makes the instrument suitable for inspection of light emitted by several elements. Here the Balmer series of hydrogen is inspected, as well as sodium and mercury. The equation for the hydrogen Balmer series is given below:

$$\frac{1}{\lambda} = 1.097 \times 10^7 |\frac{1}{4} - \frac{1}{n_i^2}| \qquad \text{Source: [5]} \tag{1}$$

II. EXPERIMENTAL PROCEDURE

The frequency of the chopper was set to a value not a multiple of $60\,\text{Hz}$ to prevent unwanted interference from electrical power supply. The voltage to the photomultiplier was set to $500\,\text{V}$ for hydrogen and mercury; however, was lowered to $300\,\text{V}$ for sodium. Similarly, the entrance and exit slits were set to $50\,\mu\text{m}$ for hydrogen and mercury; however, was narrowed to $20\,\mu\text{m}$. Both adjustments were made because the intensity of the sodium lamp was much higher than that of hydrogen and mercury, causing the signal to exceed maximum capability of the detection equipment–peaks were clipped in the graphs. During scans of the hydrogen and mercury sources, the room lighting was turned off to prevent unwanted interference.

The hydrogen scans were conducted twice. During the first scans the lamp began failing and required replacement. The second lamp was not manufactured to the same quality as the first, but was sufficiently stable for inspection. However, the first spectral line ($410\,\text{nm}$) was not confirmed in the scans. Additionally other peaks were manifested ($463\,\text{nm}$ and $587\,\text{nm}$) which suggested traces of other elements in the lamp. Identifying these elements was not within the scope of this study.

For each optical configuration (i.e., changing of the light source) a scan was taken from $-1\,\text{nm}$ to $1\,\text{nm}$ to determine the zero offset. The offset was added to the values obtained from the subsequent wide bandwidth scans to obtain accurate readings. The values reported of peaks take into account the zero offsets for each of the light sources.

Another setup concern manifested itself during a follow-on experiment. It was noted that moving the light source to an angle ($\approx 10^\circ$) from the normal to the slit causes a second peak to manifest on the zero offset measurement while lowering the position of the zero peak. Therefore it is important to keep the light source perfectly normal to the entrance slit.

III. ANALYSIS

Part One–Hydrogen. The hydrogen zero offset was determined to be (-0.02 ± 0.08) nm (see Figure 1, below). This value was added to each peak located in the hydrogen Balmer series. The Balmer series peaks were located on a wide spectrum scan (see Figure 2, below). The spectrometer was refocused to each vicinity for narrow scans to ascertain precise locations of each of the four Balmer series peaks (see Figures 3 through 6, below). The spectral line located at $\lambda = 410$ nm was not located.

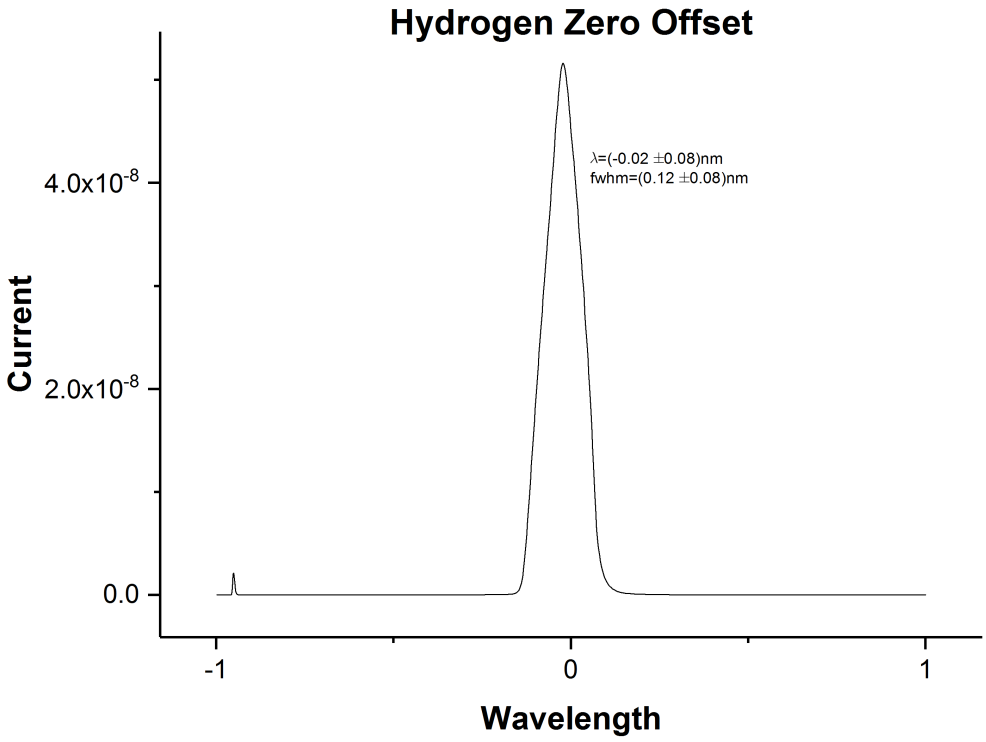

Figure 1: Hydrogen Zero Offset.

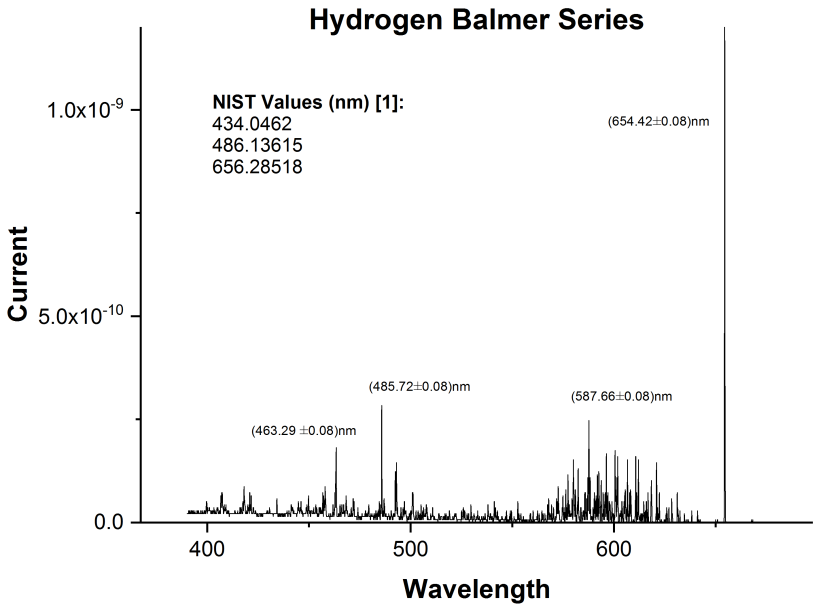

Figure 2: Hydrogen Balmer Series. The peaks located at 463.29 nm and 587.66 nm are not associated with hydrogen.

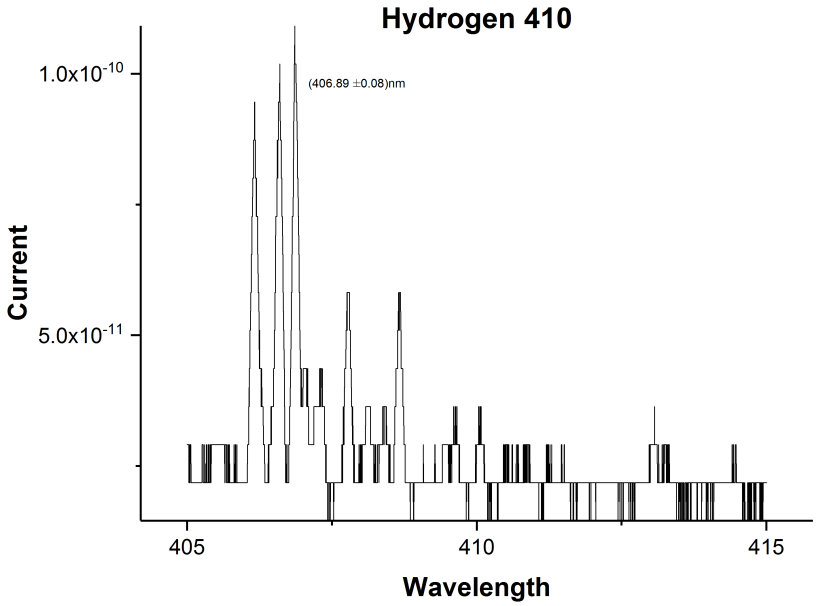

Figure 3: Hydrogen 410 Peak. The three peaks located below 410 nm are not associated with hydrogen.

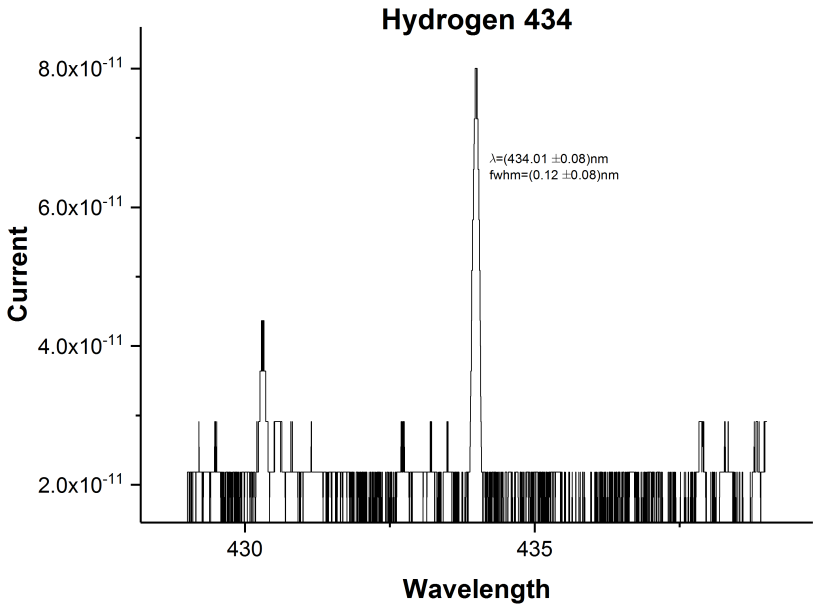

Figure 4: Hydrogen 434 Peak.

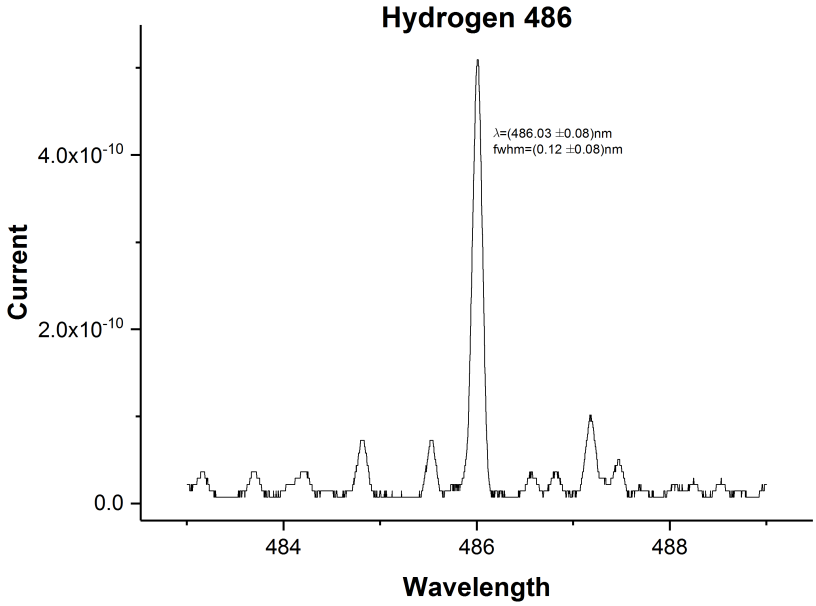

Figure 5: Hydrogen 486 Peak. Minor peaks are not associated with hydrogen.

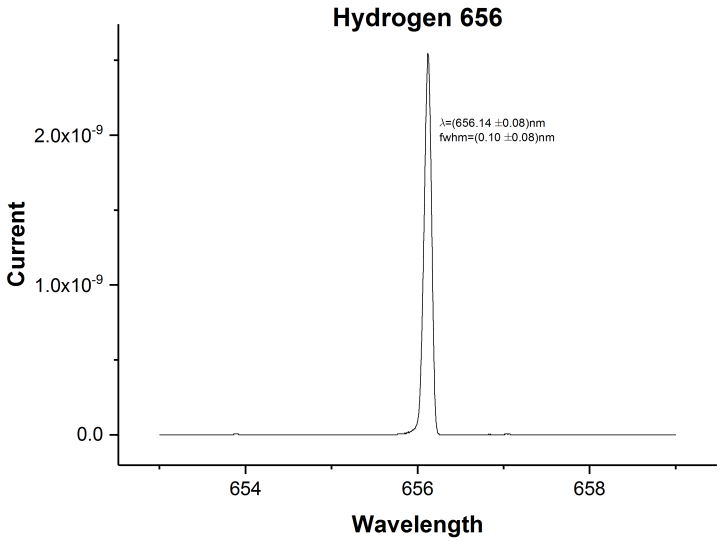

Figure 6: Hydrogen 656 Peak.

The three data points were plotted, using equation 1 (above) to confirm the value of the Rydberg Constant. The slope of the produced linear fit (see Figure 7, below) is $(1.097 \pm 0.08) \times 10^7$, which accords with the value obtained from NIST to the same significant figures[4].

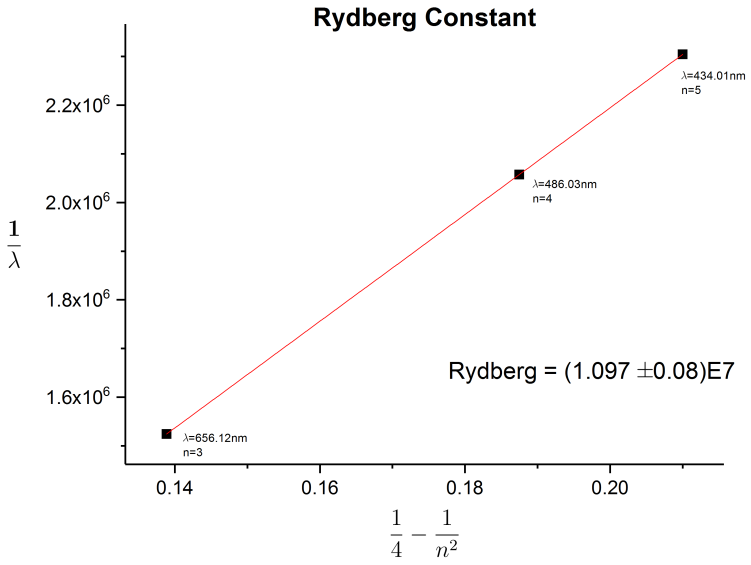

Figure 7: Rydberg Constant. The peak is located using Gaussian fit.

Part Two–Sodium. The sodium zero offset was determined to be (-0.15 ± 0.08) nm (see Figure 8, below). This value was added to the two strong peaks located in the vicinity of 589 nm. The spectrometer was refocused to this vicinity for a single narrow scan to ascertain precise locations of each of the two peaks (see Figure 9 and Table 2, below). The distance between the two measured wavelengths is (0.60 ± 0.08) nm, a difference of $< 0.1\sigma_{Na}$ from the value reported in a previous experiment[6].

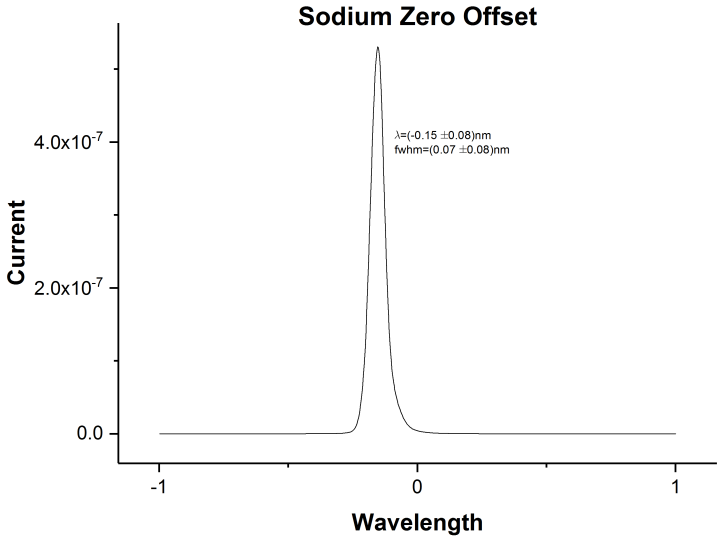

Figure 8: Sodium Zero Offset. The peak is located using Gaussian fit.

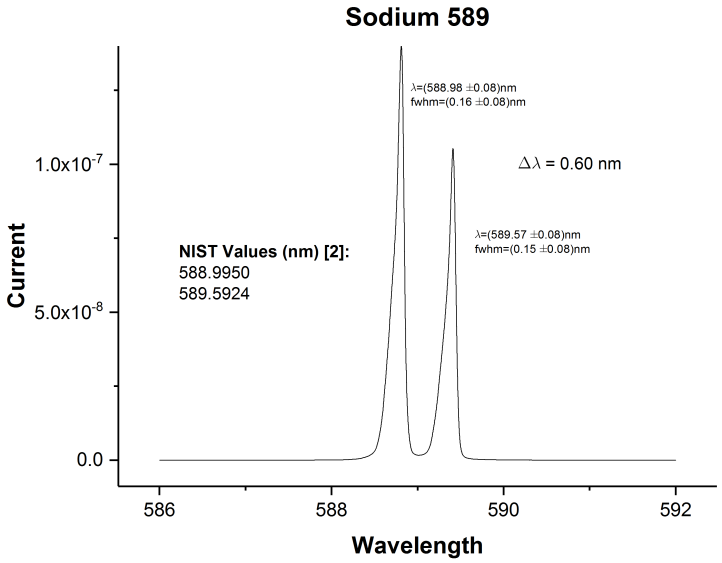

Figure 9: Sodium 589 Peaks. The peaks are located using manual cursor tracking.

Part Three–Mercury. The sodium zero offset was determined to be (-0.15 ± 0.08) nm (see Figure 10, below). This value was added to each peak located in a broad scan of the visible spectrum to locate mercury peaks (see Figure 11 below). The several peaks of mercury are listed in Table 3 (below). The wavelengths of mercury observed in the lamp conforms with mercury I. No mercury II peaks were discerned in the wavelength range inspected.

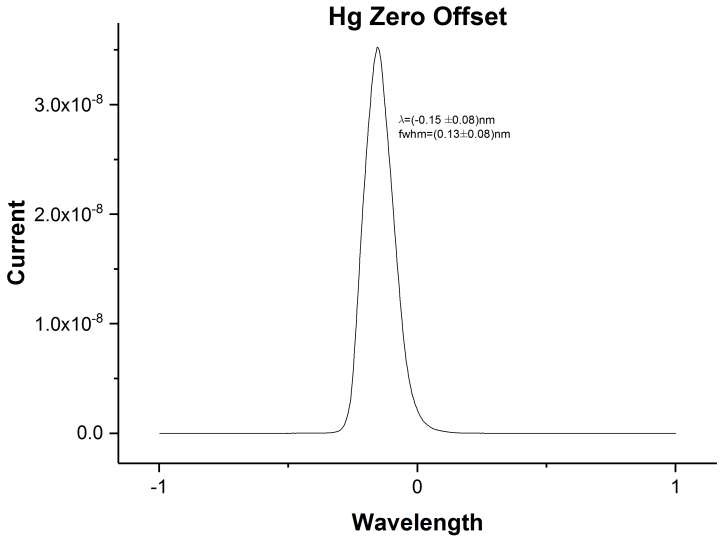

Figure 10: Mercury Zero Offset. The peak is located using Gaussian fit.

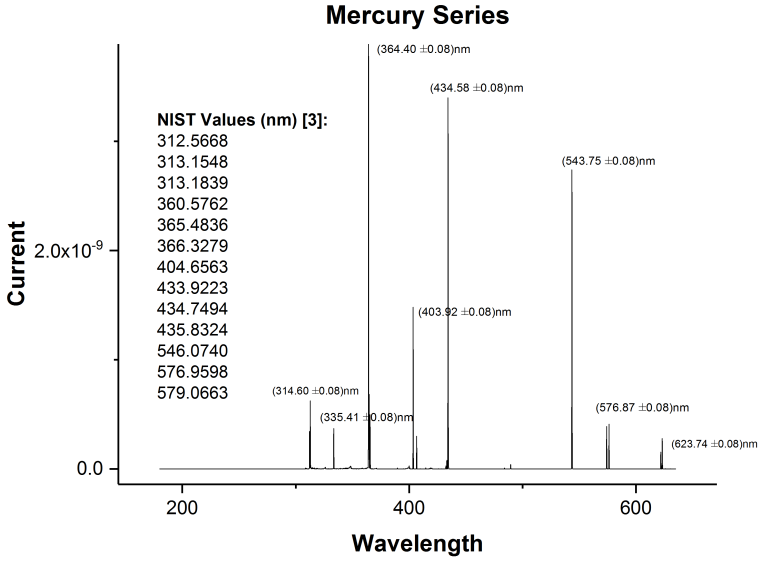

Figure 11: Mercury Series. The peaks located at 543.747 nm and 623.741 nm are not associated with mercury.

The first set of peaks were (312.52 ± 0.08) nm and (313.13 ± 0.08) nm, differences of $0.6\sigma_{Hg589}$ from the NIST reported values of 312.567 nm, 313.155 nm, and 313.184 nm respectively[3], (see Figure 12 below). NIST reports three values; however, the latter two peaks are very close in proximity and intensity. The second measured value likely encompasses both of these NIST values.

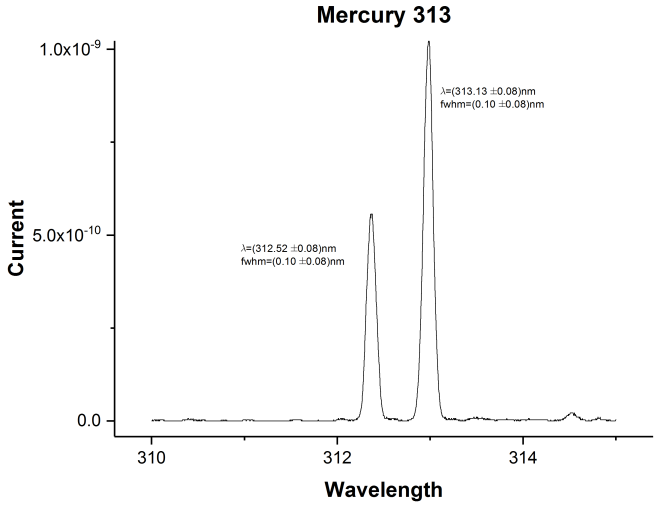

Figure 12: Mercury 313 Peaks. The peaks are located using Gaussian fit.

The second set of peaks were (365.00 ± 0.08) nm, (365.48 ± 0.08) nm, and (366.31 ± 0.08) nm, differences of $0.2\sigma_{Hg365a}$, $0.1\sigma_{Hg365b}$, and $0.2\sigma_{Hg365c}$ from the NIST reported values of 360.576 nm, 365.484 nm, and 366.328 nm respectively[3], (see Figure 13 below).

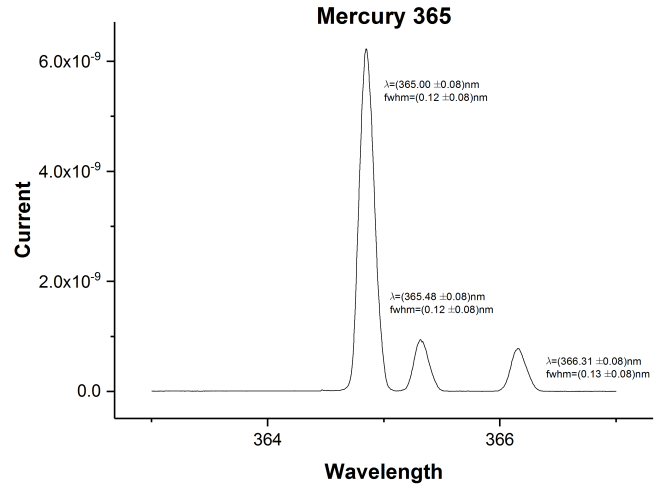

Figure 13: Mercury 365 Peaks. The peaks are located using Gaussian fit.

The third peak was (404.49 ± 0.08) nm, a difference of $0.2\sigma_{Hg404}$ from the NIST reported value of 404.656 nm[3], (see Figure 14 below).

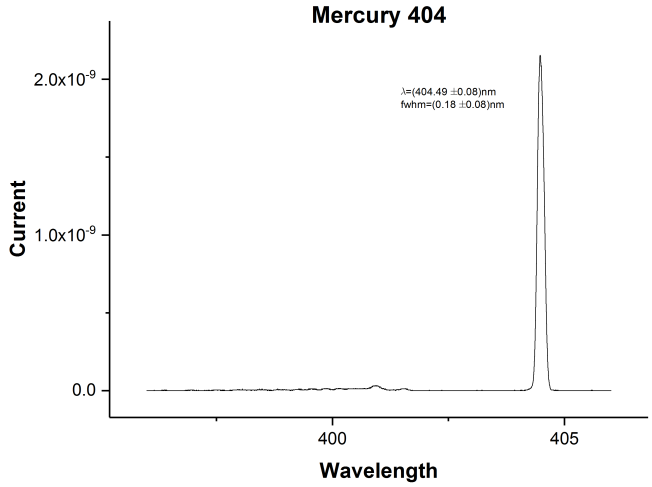

Figure 14: Mercury 404 Peak. The peak is located using Gaussian fit.

The fourth set of peaks were (433.94 ± 0.08) nm, (434.75 ± 0.08) nm, and (435.68 ± 0.08) nm, differences of $0.2\sigma_{Hg434a}$, $< 0.1\sigma_{Hg434b}$, and $1.9\sigma_{Hg434c}$ from the NIST reported values of 433.9223 nm, 434.7494 nm, and 435.8324 nm respectively[3].

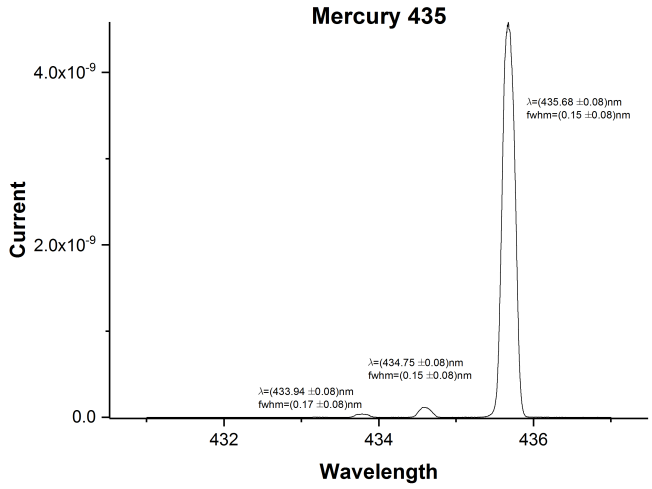

Figure 15: Mercury 435 Peaks. The peaks are located using Gaussian fit.

The fifth peak was (546.03 ± 0.08) nm, a difference of $0.6\sigma_{Hg546}$ from the NIST reported values of 546.074 nm[3], (see Figure 16 below).

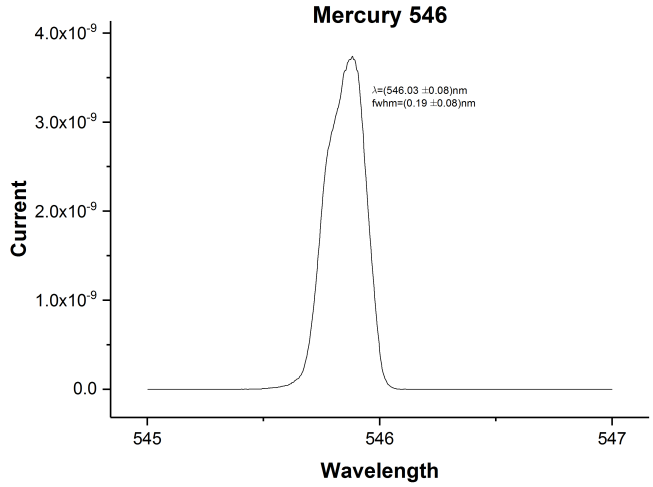

Figure 16: Mercury 546 Peak. The peak is located using manual cursor tracking.

The sixth set of peaks were (576.74 ± 0.08) nm and (578.83 ± 0.08) nm, differences of $2.7\sigma_{Hg576a}$ and $2.9\sigma_{Hg576b}$ from the NIST reported values of 576.9598 nm and 579.0663 nm respectively[3], (see Figure 17 below).

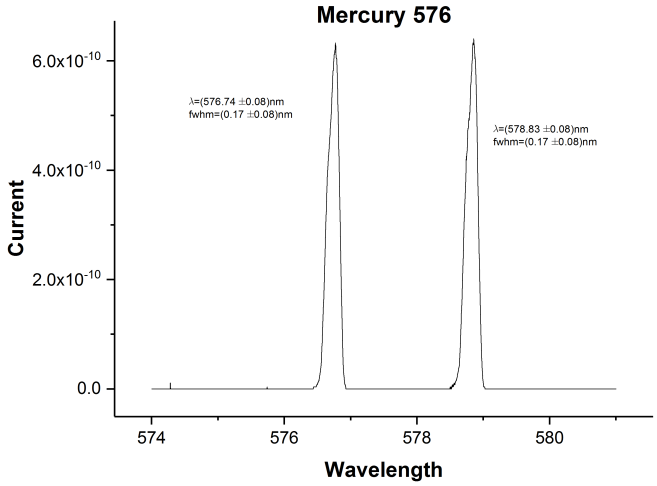

Figure 17: Mercury 576 Peaks. The peaks are located using manual cursor tracking.

IV. DISCUSSION

Three of the highest wavelength values of the four major Balmer series spectral lines were confirmed. Using these three measured wavelengths, the Rydberg constant was calculated and confirmed. The two

major spectral lines of sodium were confirmed, as well as the separation distance between them obtained from an earlier experiment. Finally, the mercury peaks were analyzed and found to conform to mercury I atom.

V. REFERENCES

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(2) NIST Physical Measurement Laboratory; "Strong Line of Sodium (Na)", http://physics.nist.gov/PhysRefData/Handbook/Tables/sodiumtable2.htm, accessed March 28, 2017.

(3) NIST Physical Measurement Laboratory; "Strong Line of Mercury (Hg)", http://physics.nist.gov/PhysRefData/Handbook/Tables/mercurytable2.htm, accessed March 28, 2017.

(4) NIST Reference on Constants, Units, and Uncertainty; "Rydberg Constant", http://physics.nist.gov/cgi-bin/cuu/Value?ryd, accessed March 28, 2017.

(5) Colbert, T.; "Spectroscopy using a monochromator", PHYS4010 Laboratory Instructions.

(6) Hartman, L. A.; "Michelson Interferometer", submitted to fulfill requirements for Augusta University course PHYS4010 on Feb 22, 2017.

(7) Belyaev, M.; "Spectroscopy and Spectrophotometry", slide presentation published at Princeton University, April 20, 2011.