Determination of the emission spectra of common gases and the Rydberg constant of hydrogen

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Abstract

Spectroscopy has major applications in modern astronomy in terms of determining the composition of distant objects based on their emission spectra. A simple experiment involving the determination of the emission spectra of common gases is performed using a Vernier spectrometer, and visualized as a plot of relative intensity vs wavelength. Each gas is determined to have unique emission peaks at specific wavelengths, allowing the identification of an objects composition based on its spectral lines. The H-α and H-β Balmer lines are observed for ^{1}H and ^{2}H, and are used to calculate the Rydberg constant for ^{1}H. Emission spectra for He and Hg are also investigated.

Keywords: emission spectra, gas discharge, Rydberg constant, Balmer series.

1 Introduction

In 1800's, various laboratories tried to explain how matter emitted light. Several scientists attempted to study until one German physicist coined the term "emission spectrum" [1]. Since then, researchers were able to produce the said spectrum but no one could explain with success. In 1905, another German physicist was able to do that. His name was Albert Einstein. [1]. He proposed how light behaved as particle (photon) and wave which was fundamental in explaining how they emitted light.

Electrons behaved in such a way that the energy of the atom was as least as possible. We call the lowest energy of an atom to be ground state. Giving energy to those atoms, electrons absorbed it and moved to the next level. Energy levels were said to be quantized, meaning they must move from one level to another level in specific steps. If potential energy was higher than the ground state, an atom was in an excited state. This was considered to be non-stable. Going back to the ground state meant that it had released energy [2].

Long before, we considered a ground state atom to be absorbing any amount of energy. We thought that the emission spectrum of a certain atom should be continuous as an electron approached the proton of the nucleus spirally, basing from classical physics. This showed wavelengths and frequencies to be represented. Thus, a continuous spectrum will be seen. An example of this can be seen through a prism as a white light strikes on it [2].

Experimentally, researchers observed a different phenomenon among atoms. A given element had a certain combination of orbital jumps. Therefore, they will be displaying a unique emission spectrum. What happened behind this phenomenon was when we apply voltage to the discharge tube, we were *heating* the tube. Electrons became excited and entered higher energy orbits. Going back to their ground state, they were able to release energy as light radiation but at specific wavelengths. These emitted wavelengths were the peaks of the graph which meant that these wavelengths values that corresponded to a color were the ones that were emitted. As mentioned above, each element has its own unique spectrum. They behaved this way because only specific orbits were allowed for each element.

The main objective of the experiment is to be able to compare and contrast the spectra of the following discharge tubes: hydrogen, deuterium, helium and mercury. Also, one of our objectives is to refresh our knowledge on using SpectroVis Plus for measuring the emission spectrum of the source of light.

This paper is organized as follows: In Section 2, we illustrate the experimental setup and materials used. In Section 3, we describe and enumerate the parameters considered and methods used in performing the experiment. In Section 4, we analyze and discuss the results. We conclude and summarize the paper and give recommendations to improve similar experiments in Section 5.

2 Experimental Setup and Materials

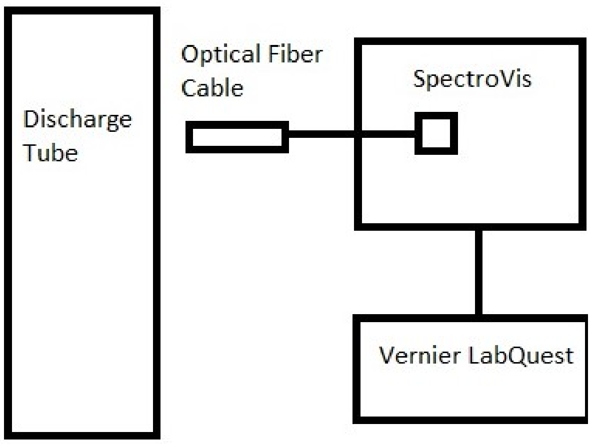

Figure 1: Schematic Diagram of the spectroscopy experiment.

The materials used in the experiment were: four discharge tubes, consisting of hydrogen, helium, deuterium and mercury; spectrum tube power supply; Vernier LabQuest for recording and analyzing the data peaks; and Vernier Spectrometer with a fiber optic cable.

3 Parameters and Methodology

The intensity versus wavelength plot for each discharge tube was determined to find the wavelengths at which peak values can be found. To do this, each discharge tube was first inserted in the spectrum tube power supply. The Vernier spectrometer, or SpectroVis, was connected to the Vernier LabQuest for data analysis. The cuvette part of the optical fiber cable was placed inside the cuvette holder of the SpectroVis. When the power supply was turned on, the tip of the optical fiber cable was aimed at the discharge tube and the Vernier LabQuest read the data and showed the peak values of the type of discharge tube being studied.

4 Results and Discussion

The data gathered from the Vernier SpectroVis were represented in terms of the relative intensity as a function of wavelength, and from the resulting plots, the wavelengths of the significant peaks were obtained and shown in Table 1.

For the hydrogen (^{1}H) source, one significant peak could be observed at 655.8 nm, along with a small notable *bump* at 478.9 nm, shown in Figure 2. These correspond to the H-α and H-β Balmer lines at 656.5 nm [3] and 486.1 nm [4], which respectively correspond to deviations of 0.1% and 1.5%. If one were to place a diffraction grating in front of the source, one would see these spectral lines as the red and cyan emissions. Since there are only two reliable data points, linear regression cannot be performed. Instead, the slope formed by the two points, shown in Figure 6, were calculated in order to determine an experimental Rydberg constant of 1.2×10^7 m^{-1}, which deviated by 5.6% from the theoretical value of 1.1×10^7 m^{-1} [5].

The deuterium (^{2}H) source exhibits the same spectral emission characteristics (shown in Figure 3) as its hydrogen-1 counterpart, the significant difference being a slight shift in the α line, located at 655.0 nm (0.8 nm difference), which deviates by 0.2% from the theoretical 656.1 nm [6].

The helium emission spectrum, shown in Figure 4 shows three significant peaks at 586.9 nm, 667.0 nm, and 705.6 nm, which correspond to yellow, red, and near-infrared emission lines. The former two spectral lines which appear in the visible spectrum deviate from the literature values of 567.6 nm and 667.8 nm [7], respectively, by 3.3% and 0.2%.

Finally, shown in Figure 5 is the emission spectrum for mercury, which exhibits peaks in the visible region at 543.8 nm, 576.4 nm, and 696.0 nm, which show up as green, yellow-orange, and red lines. The figure also shows strong emissions well into the infrared region of the spectrum. The former two visible emissions deviate from the literature values of 546.1 nm and 577.0 nm [8] by 0.4% and 0.1%, respectively.

Comparison with literature values show that the experimental data lacks in the violet-blue end of the spectrum, i.e. low sensitivity or no peaks showing up in the 400-500 nm region when literature suggests otherwise, specifically for the hydrogen and mercury emission spectra. This indicates that there may have been an error present in the spectrometer, specifically its low sensitivity for emissions smaller than 500 nm.

5 Conclusions

The emission spectra of various gas vapor lamps were plotted as relative intensity as a function of wavelength. H-α and H-β Balmer lines were observed for hydrogen and deuterium, while multiple peaks were observed for helium and mercury. Comparison with literature values placed the obtained experimental values well within acceptable error margins. An equipment error in the form of low sensitivity to short-wavelength emissions caused little to no peaks to appear in the region below 500 nm and a lack of data for the higher-order emissions of the hydrogen Balmer series. Two data points were used to calculate the experimental Rydberg constant by calculating their slope, which yielded a value of $R_H = 1.2 \times 10^7$ m^{-1}, deviating by 5.6% from the 2014 accepted value.

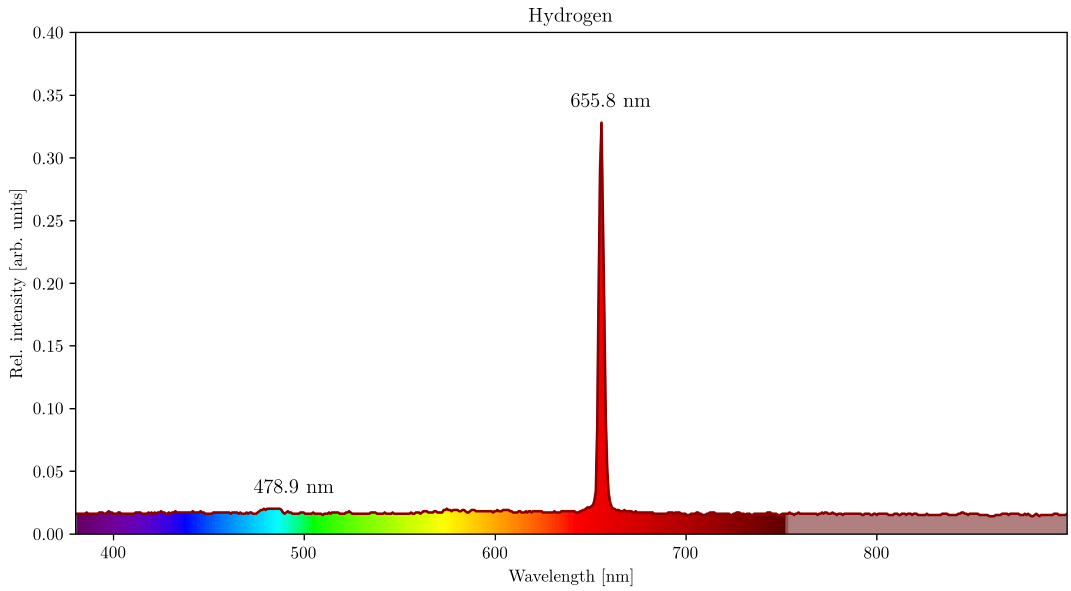

Figure 2: Emission spectrum of hydrogen.

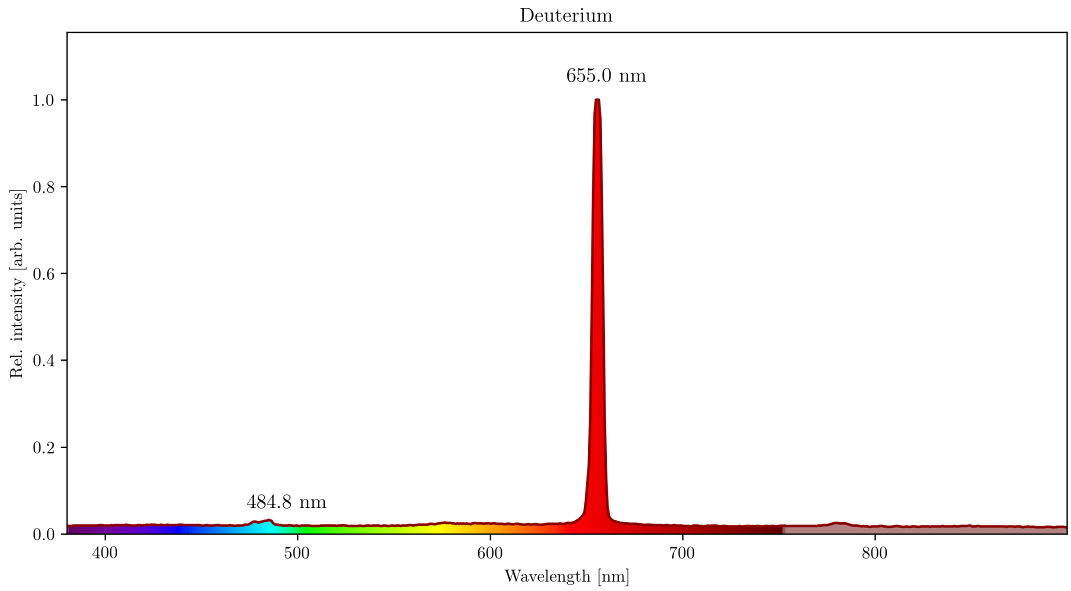

Figure 3: Emission spectrum of deuterium.

Table 1: Emission peaks for various light sources in the visible spectrum.

Light source	Wavelength(s) [nm]
Hydrogen	478.9, 655.8
Deuterium	655.0
Helium	586.9, 667.0, 705.6
Mercury	543.8, 576.4, 696.0, 768.3

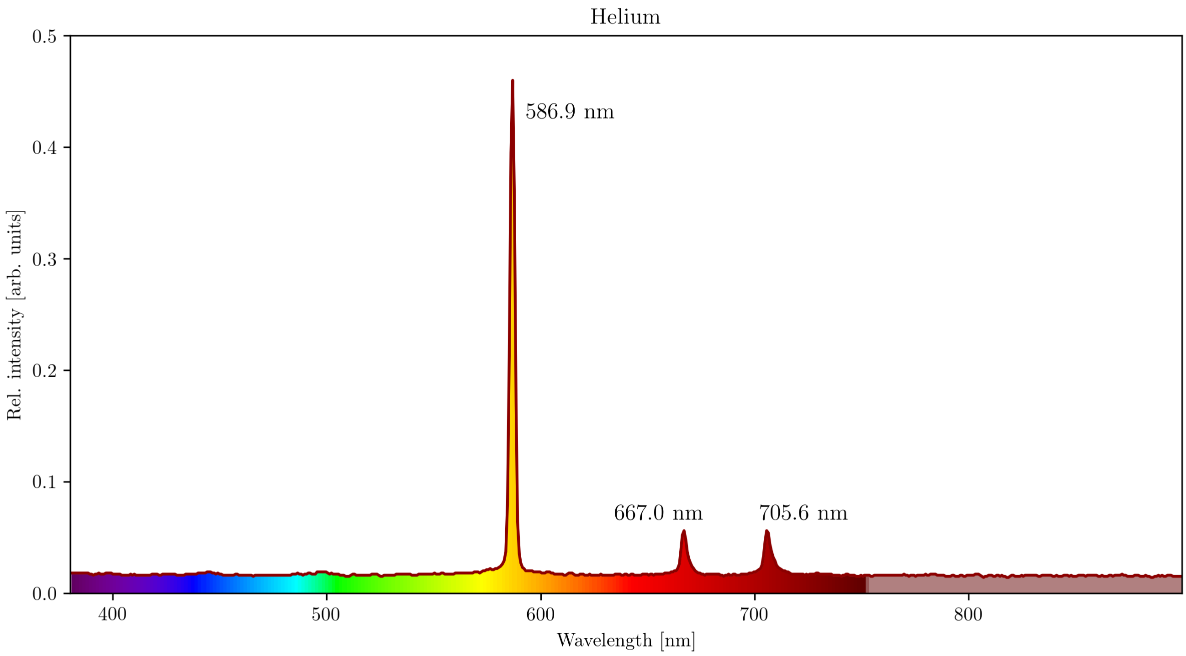

Figure 4: Emission spectrum of helium.

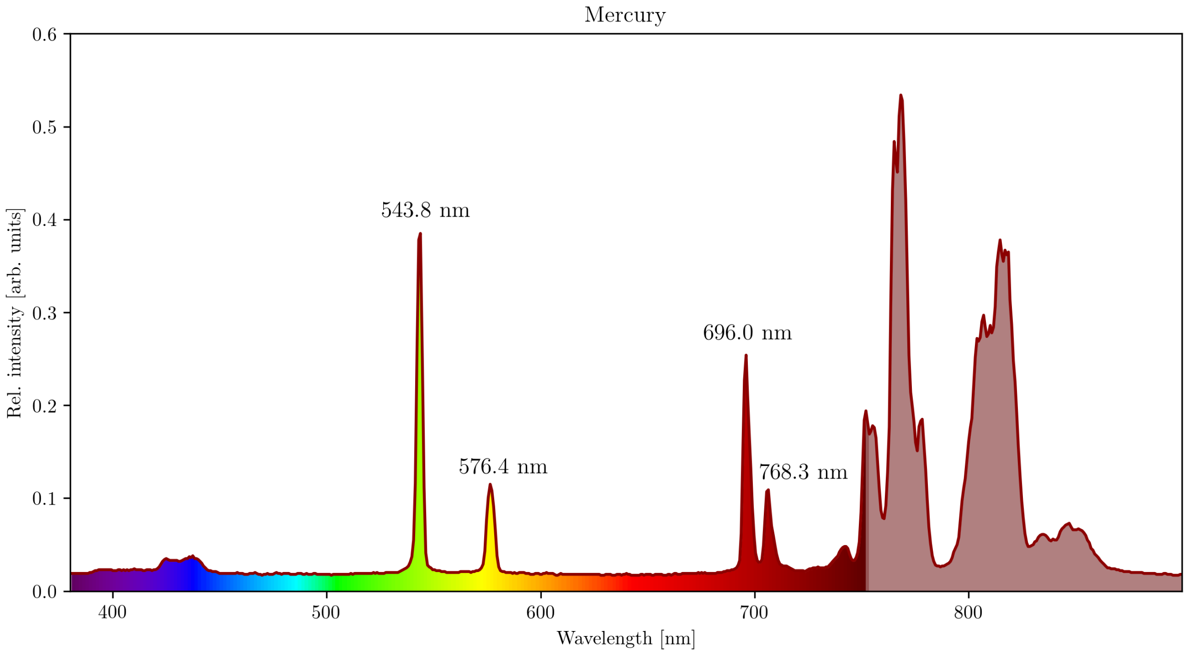

Figure 5: Emission spectrum of mercury.

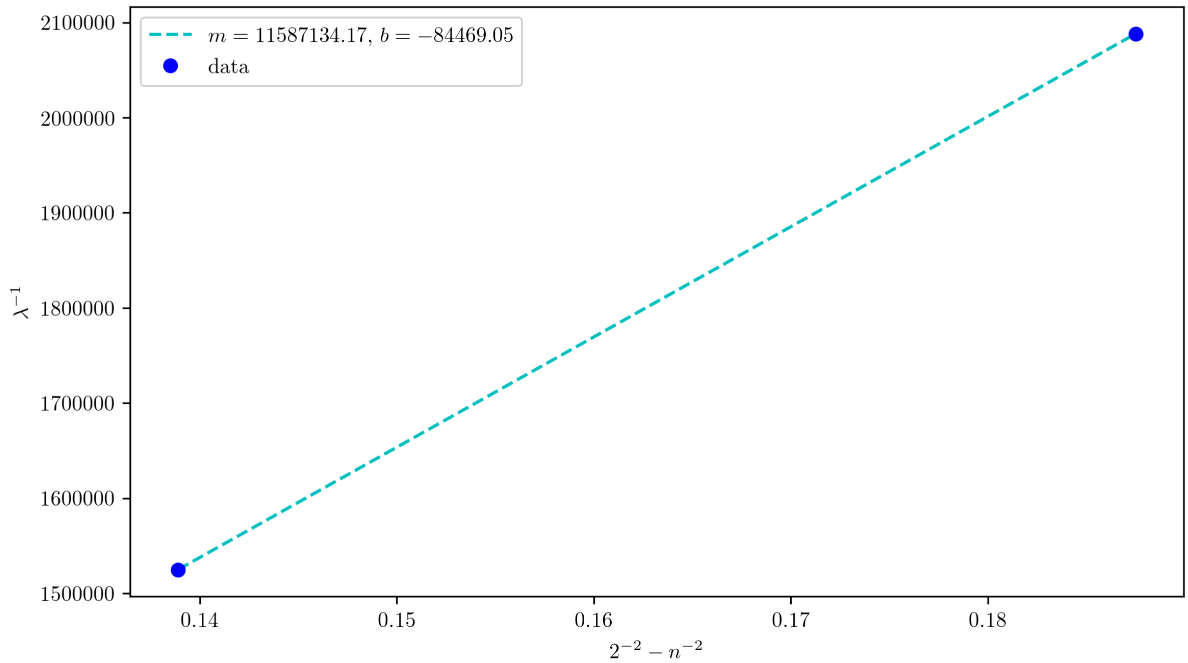

Figure 6: Balmer series of hydrogen.

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