ASTR101 Lab 2

Spectra of Gases and Solids

October 12, 2023

Arfaz, He/Him
V00984826

Objective

In this lab, my objective was to explore and analyze spectra of various light sources, gases, and elements. I conducted experiments comparing low and high-power settings of incandescent lamps, studied fluorescent lamp spectra, identified elements based on their spectral lines, and researched astronomical phenomena like Fraunhofer lines in the Solar spectrum. Additionally, I determined the colors and peak wavelengths of stars like Betelgeuse and Sirius, delving into their spectral types. I also discussed the applications of spectroscopy in studying exoplanet atmospheres and performed measurements of hydrogen spectral lines, comparing them to standard values. Despite the absence of formal measurement uncertainties, I recognized potential sources of error and suggested methods to minimize them, contributing to a comprehensive understanding of the lab exercises.

Lab Exercises

Procedures/Answers, Observations, Table/Graphs

Question 1: For the incandescent lamp, compare the two spectra corresponding to the low and high power. Explain in your own words the reasons for the differences you notice related to the overall brightness of both spectra, as well as the colors seen in each of them.

The variations observed in the spectra of the incandescent lamp at low and high-power settings are attributed to the fundamental principles of blackbody radiation outlined in the lab notes. At low power, the lamp emits light at a lower temperature, leading to a dimmer overall intensity spectrum. According to the Stefan-Boltzmann law, the intensity of a blackbody spectrum sharply increases with temperature. Moreover, Wien's law states that higher temperatures result in shorter wavelengths, or bluer light. At high power, the lamp operates at a higher temperature, emitting brighter and bluer light. In contrast, the lower power setting produces redder light with reduced intensity, explaining the differences in brightness and coloration observed between the two spectra.

Question 2: In the spectrum of the fluorescent lamp, you can see a continuum spectrum as well as bright, colored lines corresponding to an emission spectrum. Explain in your own words what causes both types of spectra to be seen.

In the fluorescent lamp spectrum, the bright, colored lines correspond to specific wavelengths emitted when gases like mercury vapor are excited. These lines form the lamp's emission spectrum.[2] Additionally, the lamp emits light across a range of wavelengths, creating a continuum spectrum, as explained in the lab notes. Therefore, the presence of both emission lines and a continuum spectrum in the lamp's spectrum is due to the excited gas emitting specific wavelengths and emitting light continuously, respectively. [2]

Question 3: Identify the six elements for which the spectra are shown in Figure 3. In your report, write a brief description of each spectrum (the colors of the spectral lines visible, their numbers, relative brightness, etc.). For each element, mention which spectral lines helped you identify the element (using their colors or positions in the spectrum).

Spectrum 1 = Sodium (Na)
Spectrum 1 shows bright yellow lines, specifically the Sodium D lines (D1 and D2), which are closely spaced and indicative of sodium.

Spectrum 2 = Hydrogen (H)
Spectrum 2 displays colored lines, including prominent blue (H-alpha) and red (H-beta) lines, representing hydrogen's characteristic Balmer series transitions.

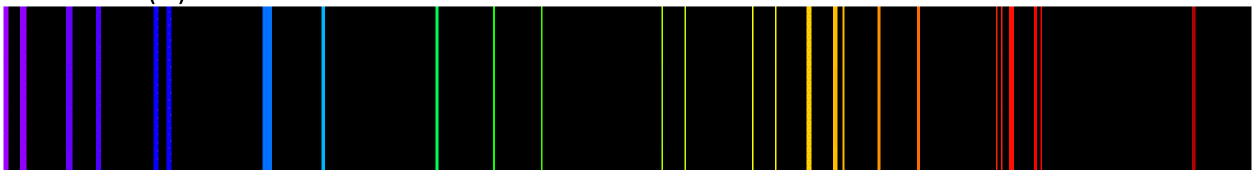
Spectrum 3 = Oxygen (O)
Spectrum 3 exhibits distinct green and red lines, unique to oxygen, with green lines arising from oxygen molecules and red lines from atomic emissions.

Spectrum 4 = Nitrogen (N)
Spectrum 4 reveals green and red lines, like oxygen but with specific transitions in nitrogen atoms and molecules.

Spectrum 5 = Iron (Fe)
Spectrum 5 shows numerous blue and green lines typical of iron, with specific patterns aiding in its identification.

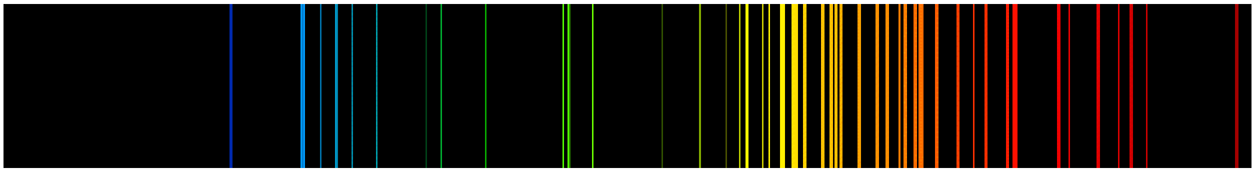
Spectrum 6 = Mercury (Hg)
Spectrum 6 displays various bright lines, including characteristic blue and green lines specific to mercury, allowing its recognition.

• Uranium (U)



Uranium's spectrum typically features a series of lines in the violet and ultraviolet regions. The lines are numerous and intense, indicating high energy transitions. One of the key lines used for identification is often the intense violet line, which is specific to uranium and helps distinguish it from other elements.

• Neon (Ne)

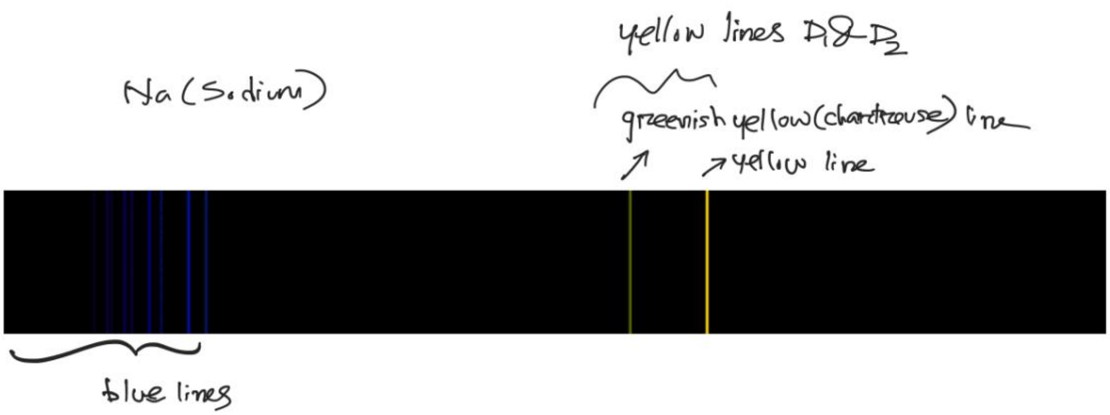


Neon's spectrum is characterized by bright, colorful lines in the red, orange, yellow, and green regions. These lines are distinct and well-defined, with the prominent red lines being particularly noticeable. The specific shade of red and the presence of other lines in the visible spectrum, such as orange and yellow, are used to identify neon.

• Sodium (Na)

Sodium's spectrum displays yellow lines, known as the Sodium D lines (D1 and D2). These lines are intense and closely spaced. The characteristic yellow color and the specific positions of D1 and D2 lines in the spectrum are unique to sodium and aid in its identification.

<u>Question 4: From all the elements shown on the online app, choose one as your favorite chemical element. Using the online app, find out what its emission spectrum looks like and sketch and describe the spectrum in your report. If you do not have access to proper color pencils, mark the approximate locations of the lines and name their colors.</u>



<u>Question 5: In the Solar spectrum, some of the absorption lines are broader and very clearly seen. With some research, find out the name by which astronomers refer to these lines, and write a brief description of these set of absorption lines.</u>

Fraunhofer lines are dark absorption lines in the solar spectrum, indicating specific wavelengths of light absorbed by elements in the Sun's atmosphere.[3] Named after the German physicist and astronomer Joseph von Fraunhofer, these lines are dark lines observed in the solar spectrum, indicating absorption, or blocking of specific wavelengths of light by chemical elements in the Sun's outer atmosphere.

Question 6: Name at least two chemical elements (=atoms) which cause these absorption lines in the Solar spectrum.

Two chemical elements that cause absorption lines in the Solar spectrum are Hydrogen (H) and Helium (He).

Question 7: What does the presence of these chemicals in the Sun tell us about its age and formation history?

The presence of hydrogen and helium in the Sun's spectrum indicates standard stellar formation. It doesn't provide specific details about the Sun's age or formation history.

Question 8: As discussed earlier, the color of a star is related to the peak wavelength in its spectrum and indicates its temperature and other properties. Using the online app, find out the color and peak wavelength of the star, Betelgeuse, (in the constellation Orion), if the surface temperature of the star is 3500"K.

Color	: Red
Peak wavelength	: 860 nm

Question 9: Using some research, find out what type of star Betelgeuse is. Does the color your determined match the expected color of the star, based on its type?

It does match. Betelgeuse, being a red supergiant with a surface temperature of around 3500 K, emits its peak intensity in the infrared spectrum, approximately at 1 micron wavelength. Although our eyes cannot detect infrared light, the peak intensity in the visible spectrum corresponds to red, which is why Betelgeuse appears red to us despite its infrared peak.

Question 10: Using the online app, find out the color and peak wavelength of the star, Sirius, (in the constellation Canis Major), if the surface temperature of the star is 10000"K.

Color	: White
Peak wavelength	: 300 nm

Question 11: What is the spectral type of the star, Sirius? Explain whether the color you determined matches the expected color based on the star's spectral type.

It does match.

The spectral type of Sirius is **A1V**. A1 stars are white main sequence stars, and V stars are stars that are fusing hydrogen in their cores. A1 stars are white, and the peak wavelength of a blackbody with a temperature of 10000 K is in the ultraviolet range.

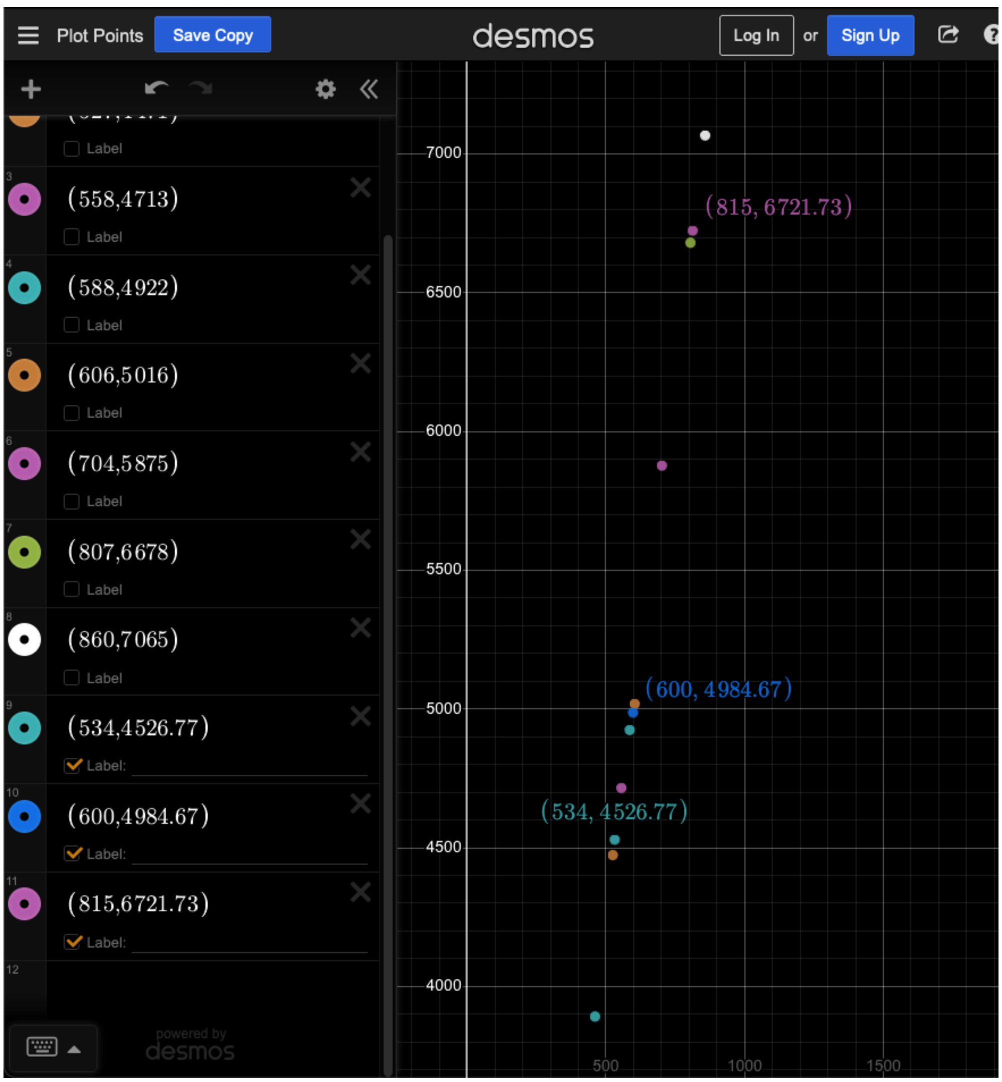
Question 12: If the spectrum of a star peaks in the green region of the visual spectrum, using the app, I would estimate its surface temperature and peak wavelength to be:

Surface temperature: **7000 K**
Peak wavelength: **530 nm**

Question 13: How can spectroscopy be used to learn about extrasolar planet atmospheres? What type of spectrum would be observed? What makes this type of observation particularly challenging?

Spectroscopy is a powerful tool for learning about the atmospheres of exoplanets. By observing the light that passes through the atmosphere of a transiting planet, astronomers can infer the composition of the atmosphere. This type of observation is challenging because the amount of light is very small, but it has already been used to learn a great deal about exoplanets. [1]

Question 14: What are your measured wavelengths of the H_α, H_β and H_γ spectral lines?



Using Desmos and Slope Formula,

$$y = y_1 + \frac{(x - x_1)(y_2 - y_1)}{(x_2 - x_1)},$$

I found the wavelength of $\boldsymbol{H_\alpha}$ to be **6721.73 Å**, $\boldsymbol{H_\beta}$ to be **4984.67 Å** and $\boldsymbol{H_\gamma}$ to be **4526.77 Å**.

Question 15A: Physics data books give the wavelengths of the Hydrogen lines as 6563 Å for H_α, 4861 Å for H_β, and 4340 Å for H_γ. By how many Å do your measurements differ from these standard values?

Line	Measured wavelength (˚ A)	Standard wavelength (˚ A)	Difference (˚ A)
H_α	6721.73	6563	158.73
H_β	4984.67	4861	123.67
H_γ	4526.77	4340	186.77

Question 15B: Are the differences the same for all three lines? Of the three spectral lines, which line is the most discrepant from the standard value?

No, the differences are not the same for all three lines. The H_γ line is the most discrepant from the standard value, with a difference of 186.77 ˚A.

Question 16A: In the analysis, we have not done a formal estimate of measurement uncertainties and errors in your results. However, in your own words, describe at least two sources of measurement uncertainties, and how they will impact your results.

1. **The accuracy of the pixel ruler:** The pixel ruler in GIMP is a very precise tool, but it is important to use it correctly. It is important to make sure that the ruler is aligned with the spectral lines.
2. **The resolution of the image:** The resolution of the image will also affect the accuracy of the measurements. A higher resolution image will allow for more precise measurements.
3. **The human factor:** It is also possible for human error to introduce uncertainties into the measurements. i.e., if the user does not carefully align the pixel ruler with the spectral lines, then the measurements will be inaccurate.

Question 16B: Suggest possible ways by which these uncertainties may be reduced?

1. **Use a high-resolution image:** As mentioned above, a higher resolution image will allow for more precise measurements.
2. **Repeat the measurements multiple times:** This will help to reduce the impact of human error.

3. **Use a calibration grid:** A calibration grid can be used to check the accuracy of the pixel ruler. The calibration grid can be created using a known light source, such as a mercury lamp.

Conclusion

The spectroscopic analysis conducted in this lab provided valuable insights into the behavior of light emitted by various sources and allowed me to identify elements based on their unique spectral patterns. I learned about the principles of blackbody radiation, emission, and absorption spectra, and their applications in understanding celestial objects like stars and exoplanets. Despite some discrepancies in the measured wavelengths, likely due to uncertainties in measurement methods, the overall experience enhanced my understanding of spectroscopy and its significance in astrophysical research.

References:

[1] Spectroscopy. [Online]. Available: https://en.wikipedia.org/wiki/Spectroscopy

[2] Emission spectrum. [Online]. Available: https://en.wikipedia.org/wiki/Emission_spectrum

[3] Fraunhofer lines. [Online]. Available: https://en.wikipedia.org/wiki/Fraunhofer_lines

[4] Sodium. [Online]. Available: https://en.wikipedia.org/wiki/Sodium

[5] Hydrogen. [Online]. Available: https://en.wikipedia.org/wiki/Hydrogen

[6] Oxygen. [Online]. Available: https://en.wikipedia.org/wiki/Oxygen

[7] Nitrogen. [Online]. Available: https://en.wikipedia.org/wiki/Nitrogen

[8] Iron. [Online]. Available: https://en.wikipedia.org/wiki/Iron

[9] Mercury. [Online]. Available: https://en.wikipedia.org/wiki/Mercury

[10] Uranium. [Online]. Available: https://en.wikipedia.org/wiki/Uranium

[11] Neon. [Online]. Available: https://en.wikipedia.org/wiki/Neon

[12] Emission Spectrum by Elements [Online]. Available: https://web.archive.org/web/20160619184630/http://chemistry.bd.psu.edu/jircitano/H.gif