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Analysis of Shifts in Black Body Spectra

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Phys 2210: Exploring Experimental Physics

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May 8th, 2023

Abstract:
It follows from our intuition that the atmosphere appears to change color depending on the time of day and our lab group was concerned if we could quantitatively observe this premise by analyzing the visible spectra. This initially required the creation of a home-made spectrometer and software that could process the spectra images taken. We tested our setup with gas lamps (known spectra) to verify our methodology. We then took photos of the atmosphere at approximately 4:00pm and 15 minutes after sunset. Upon observing odd peaks within our intensity graphs, we then studied a lightbulb, a decent approximation of a black body, to have a controlled experiment in which we could isolate why our intensity graphs appeared off. This showed that our camera, an iPhone, was not a reliable tool to record images of spectra accurately.

Introduction:
Black bodies are fundamental to understanding the cosmos around us, penetrating how their radiation works serves as a foundation to understanding how radiation operates throughout the universe. Our group wanted to study how spectrometers could be used to study black body spectra under various conditions. With an awareness that some Physics 2210 experiments are used as inspiration for outreach programs it was important to our group to try to use minimal, readily-available materials to accomplish our task. This resulted in a spectrometer made from a UHAUL box and the use of a phone camera as our optical sensor. Though this set up accurately tracked intensity on a single wavelength, and we were able to achieve more precise measurements for the wavelengths of different spectra, we were unable to get clean results on both intensity and wavelength for black-body spectra. This is likely due to bias within the phone camera as we are very confident in the apparatus that we constructed. Thus, instead of really investigating black bodies, this lab's results might have been more helpful towards the analysis of how phone cameras edit the light that comes into the phone camera and uncover some of how that software works.

Description of Experiment:

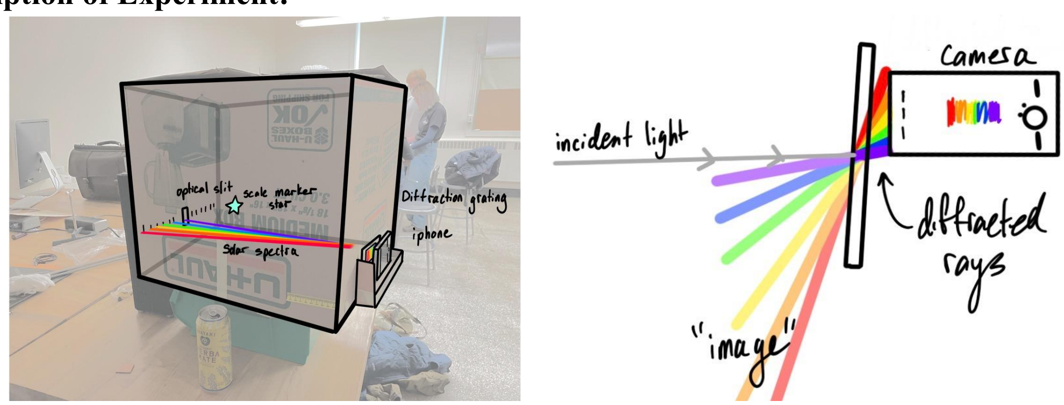


Fig 1: Diagram of our Spectrometer and diffraction of light rays within

The basic setup of our spectrometer apparatus consisted of a large box, a diffraction grating, a glow in the dark star, and a phone camera. To minimize glare, especially in day time images, we also included a felt lining, various materials to create smaller optical slits, and a tape flap to block extra light from getting on the phone camera (not pictured).

The experiment is divided into 3 parts, but the overall procedure remains the same: the box is pointed towards the light source and a preliminary image is taken of the spectra on the phone screen. If there is too much light in the box, the optical slit is exchanged for a smaller version. The slits used in the experiment included a custom metal ruler with a large, almost ¼cm slit through the middle, stiff paper cut with a box knife to about 1 or 2 mm, and finally foil cut with a razor blade to the thinnest possible slit that allowed for light to pass through. Once the correct slit was selected, the phone then takes a screenshot of the data as it appears on the camera app before taking the photo. This is done to avoid the effects of deep fusion, an iphone program that re-adjusts saturation levels after an image is taken.

The first section of this lab deals with taking the spectral lines of gas lamps. This served to both calibrate the MATLAB program and to confirm that our program could accurately measure wavelengths. In this part of the lab, a He or Hg lamp was allowed to heat and then placed very close to the spectrometer box. Using the large metal ruler slit, the gas lamp produced distinct spectral lines which were measured and quantified in MATLAB.

Figure 2: Filament bulb set up (after the bulb was burnt out)

The second section deals with a tungsten filament bulb. The data is taken also with the largest, metal ruler slit. By heating the filament to where the bulb burns out, it can be assumed that the voltage at which the filament burnout was the voltage that causes the filament to reach the melting point of Tungsten. Measuring from 3.5V and increasing by .5V increments, the voltage and current going through the bulb were measured. The relationship between the temperature of the filament bulb and the voltage it was being supplied could be estimated by relating the temperature to the resistivity of the wire within the bulb. We used the following equations to create a function of temperature as a function of R or rather the Voltage/Current.

Resistivity of Tungsten: $\rho = \alpha T$ where $\alpha \approx 0.02585$

Resistance: $R = \frac{\rho l}{A} = \frac{I}{V}$

Since bulb melted at $R = 9.311\Omega$ and $\frac{l}{A} = \frac{V_f}{I_f(T\alpha)}$ then $\frac{l}{A} = 0.0974$.

Now we can express T as a function of $\frac{V}{I}$ or rather R.

$$T = \frac{R}{(0.0974\alpha)}$$

By comparing the black body emissions taken on the phone to the predicted emissions from the mathematical blackbody model under a specific temperature, we could observe how our data did or did not follow the trends we expected it to.

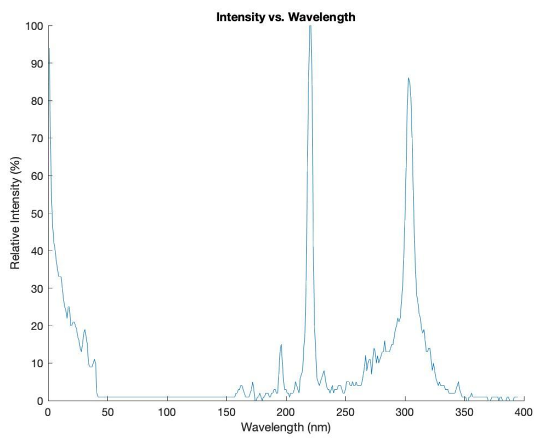
Fig 3. Data collection in the rain

Finally, the last part of the experiment was to measure solar spectra. These were the most difficult to take. In addition to using the foil slit, umbrellas, towels and other impromptu methods of taking data in the rain or in overly bright conditions were needed to get an image that wasn't over exposed without getting the box wet. Images were taken around 4pm and around sunset. The idea was that at 4pm the sky would be bright blue and at sunset it would be red as the sun had to pass through more atmosphere. However, it was, as previously mentioned, cloudy and the images were more often just varying shades of grey. This led to the use of the black body for a more controlled range of spectra.

Presentation of Data:

MATLAB code was used to analyze the images taken using the spectrometer. Analysis consisted of cropping the image to include only the slit and the right edge of the box, using the glow-in-the-dark star as a marker. The star was dim enough to not have any obvious effects on our data since our measurements look identical to ones taken without the star. The image is then analyzed by MATLAB's built-in rgb2gray function, and one row of pixels is selected to be representative of the spectra (we typically used the middle). The intensity of the pixels are then plotted against their positions.

In order to calibrate our x-axis so that the position of the pixels corresponds to the appropriate wavelength, we analyzed the well-known emission spectra of two ionized gasses: hydrogen and mercury. Our calibration consisted of finding two values: a scale factor and an offset factor. We identified the pixel positions of the leftmost and rightmost peaks in intensity using an uncalibrated graph, then using that we scaled the graph so that the difference between these two peaks is the same as the distance between the actual wavelengths of the spectra. For example, with hydrogen we observed the rightmost peak to be at pixel 303 and the leftmost peak to be at pixel 196. The actual values these peaks correspond to are 656 nm and 434 nm, and so scaling the x-axis by a factor of ~2.07 separates the peaks by the correct distance. Finally, we shift the graph by the difference between the observed (scaled) and expected leftmost peaks (434-(196*2.07)≅27 in this case), resulting in a graph with all peaks plotted at their proper wavelength.



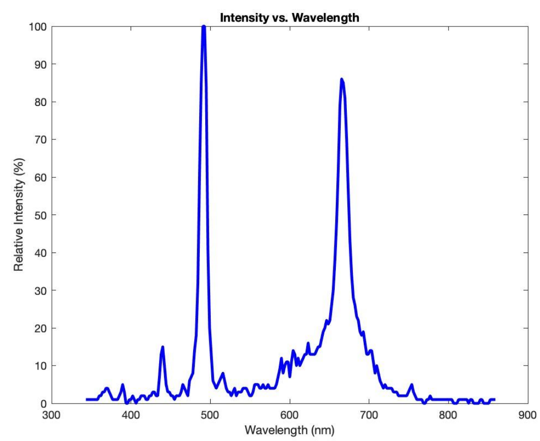


Figure 4. Both graphs depict the emission spectrum of hydrogen. The left graph is uncalibrated and depicts raw (normalized) data. The right graph has been calibrated and cleaned up (lines made thicker and irrelevant data removed).

We used the average of the values calculated from both mercury hydrogen and mercury to scale and offset the rest of our images (these values were also scaled by factors of the width of the image to account for differences in resolution). This approach appears to be effective since all of our measurements fall within visible wavelengths and qualitatively matches what we see in the image. The graphs were also normalized using the largest intensity value so that differences in intensity due to the camera or the overall brightness of the subject were minimized. This helped us in our analysis of how the spectrum changed without having to account for overall brightness.

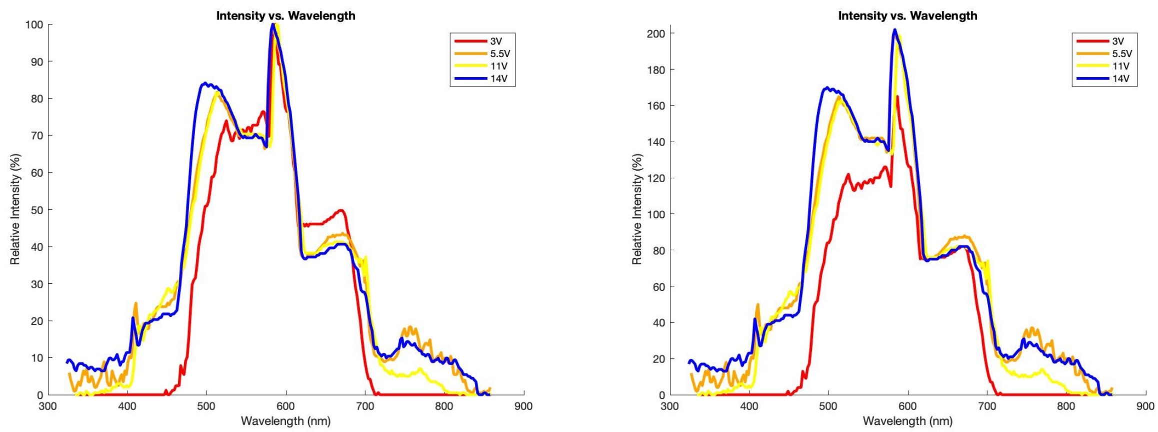


Figure 5. Both graphs depict a selection of data taken of a blackbody (lightbulb). The left graph shows the normalized data, while the right shows the raw data. The lower voltages have a lower intensity in the right graph because the lightbulb was not as bright. Although, as shown in the left graph, the spectra itself is changing as well.

To begin, we find that the light-bulb has a shift in spectra that we would anticipate. To first reiterate some context, we chose this light-bulb since it acts as a decent approximation of a black body. More specifically, the light-bulb initially had a red glow at lower voltages to white as voltages increased. Seeing the graph above, specifically at the extremes, the lowest voltage has much more relative red intensity, than the 14 volt graph, which has significantly more blue. Also, we see an oddity within our graphs: the three distinct peaks found in all three images taken. In order to fully investigate the implications of these peaks, it will take our construction of a black body model.

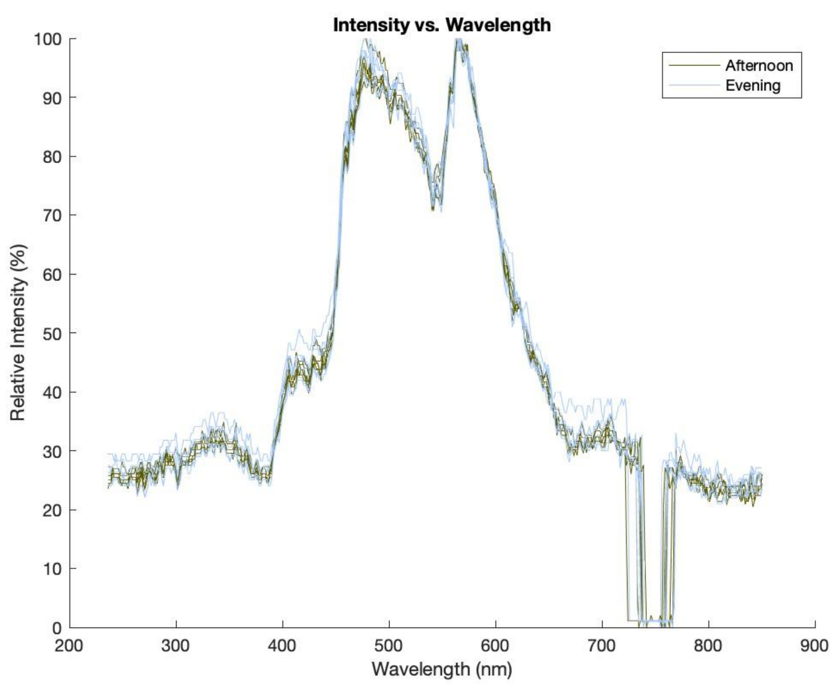


Figure 6. A normalized graph depicting data collected by imaging the sky at different times of day. Note that the sudden drop on the right hand side is due to manually editing out part of the camera GUI. As the graph shows, there is no notable difference between spectra taken during the day versus spectra taken at sunset.

Surprisingly, there appears to be no observable difference between the photos taken during the day versus those taken during sunset. While this may seem wrong, this was an anticipated result from our group. The reason for this is due to where these shifts in color occur. On clear days, during sunset, the sky appears a deep blue while the horizon shifts towards a more orange/red color. Unfortunately, it was not reasonable for us to capture images of the horizon, since there would be too much noise between us and the atmosphere in the forms of trees, houses, etc. As a result, we often were comparing a blue sky at two different times, hence the non-distinctness between the two graphs. The most notable feature of all of these graphs is the sharp peak at ~575 nm. This peak is consistent for all images we take, and we believe it to be a result of the iPhone camera manually adjusting intensities to make yellow more vibrant, or perhaps the iPhone camera itself is more sensitive to yellow light. We are confident that this is not an artifact of our analysis for two reasons. The first is that MATLAB only analyzes a grayscale version of the image, and the second is that our code can correctly identify peaks using "perfect" data without noise (see Figure 7).

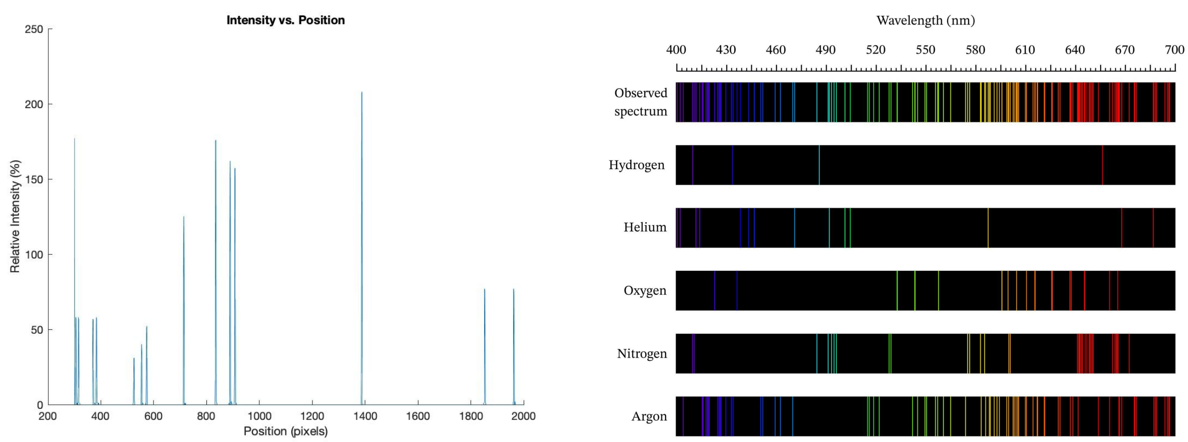


Figure 7. Our generated graph (left) analyzing an internet image of the helium spectrum (right) (Image credit: nagwa.com).

We also examined the relationship between our plots with the predictions of a black body simulation. Using the earlier equations, the temperature of the bulb could be approximately inferred from the voltage it was being supplied with and the black body curves could be properly estimated. We plugged in the equation for the black body into Mathematica to simulate the curve at our estimated temperatures.

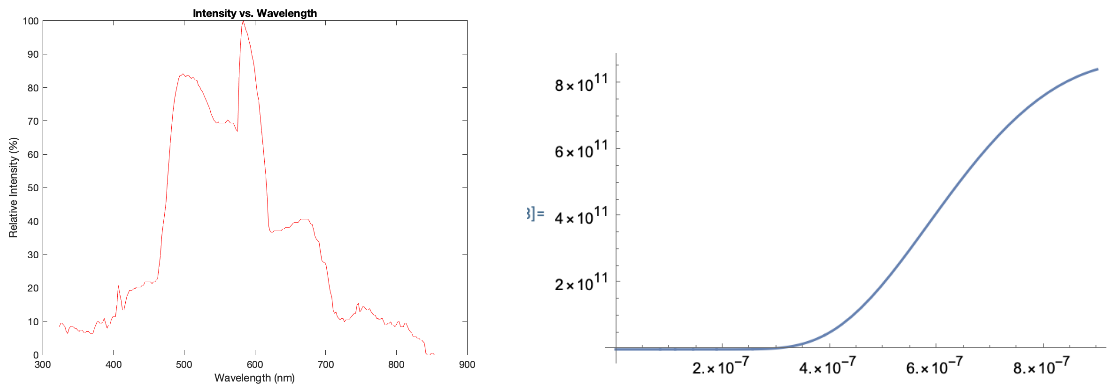


Figure 8. Mathematica Plot of Temperature as a function of wavelength and Intensity vs Wavelength Plot

We found that our plots were not matching up exactly with the graphs given by the Mathematica model. There are few reasons we believe for this discrepancy. One could be that the phone is shifting the data in the same way that it is boosting the yellow spectrum. Another idea could be that our scaling method in Matlab is off by some factor. However, given that for the curve that we measured to be given by the model, the temperature would have to be much hotter than would be likely possible in the light bulb. Also, our testing with the spectrometer and finding results that matched online makes this less likely. Finally, the main source of error in the comparison could be that our temperature prediction function has large uncertainties. Comparing it with data online our temperature predictions, while not being completely accurate, seem to be in a reasonable range for the temperature of the Tungsten bulb. In conclusion, we learned from the temperature that the phone's software is probably involved with the shift that we see in the graphs compared to the perfect black body model.

Conclusion:

Unfortunately, while our group came in with the intention of scientific discovery, upon completing this experiment, we are left with more conclusive evidence that the iPhone camera causes a bias towards certain wavelengths in the visible spectrum. While that severely impacted the conclusiveness of our evidence, it is still worth reiterating some of the successes had during this experiment. In the discussion of the light-bulb, though the exact relative intensity is inexact and fails to capture the complete picture of our system, there is still a notable evolution from red to blue as the voltage of the light-bulb increased. Here, as already mentioned, we were able to observe the evolution in our "controlled black-body." In terms of procedure, we were able to develop a sophisticated bit of software that accurately measured the relative intensities of visible wavelengths. Furthermore, we were able to capture dozens of quality images of spectra using a simple cardboard box and diffraction grater.

However, even with these successes, it ultimately amounted to inconclusive results about spectra related to the atmosphere. With that being said, our experiment posed two potential theories for why we got the data we did, both relating to the iPhone camera we used to take pictures. First, is that the three peaks were associated with software built within the iPhone to purposely manipulate images to make them more appealing to the human eye. We are aware of a software known as DeepFusion that seemed to alter images when one tried to capture a dark photo without flash. While we thought we could avoid this software by taking screenshots, it appears the images were still being artificially manipulated in some fashion. The other possibility theory is the peaks (of which there are three that are prominent in the light-bulb data) that are associated with the RGB values of a camera. While an option, we are somewhat more skeptical of this theory due to the third peak (around the 700 nm range) not appearing in our atmospheric spectra data.

Overall, in our attempt to prod for a deeper understanding of the natural world around us, we instead found interesting behaviors in the man-made.