Blackbody Radiation

Adams, Jake
jake.adams@mail.utoronto.ca
1003847377

Jiang, Hansen
hansen.jiang@mail.utoronto.ca
1003192403

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Introduction

The purpose of this experiment was to use an incandescent light bulb and a prism spectrophotometer to measure the bulb's blackbody spectrum, and to demonstrate the inverse relationship between the source's temperature and its peak intensity wavelength.

Methods and Materials

- Prism Spectrophotometer
- incandescent bulb light source
- collimating lens
- Blackbody Radiation Labview application
- Broad Spectrum Light Sensor

Experimental Procedure

To begin, the scanning arm was rotated counterclockwise until it could go no further, as this is the starting position for each scan. The light sensor gain was set to 10x and in the Labview application, the angle of acquisition was set to 80 degrees. For the first scan, the voltage was set to 6 V. After making a few observations of the color of the light source and its resulting spectrum, the experiment was initiated. The scanning arm was slowly brought through its rotation so that the spectrum could pass through the light sensor, until the automatic shut off was met. The labview application then produced a plot of the light intensity vs. angle and the data was recorded. With the labview application still set on the 80 degree acquisition, the experiment was reset to starting position and repeated for varying voltages between the range 4 V to 10 V. For each voltage interval of 0.5 V, the current and angle of the main peak on the plot were recorded. Additionally, the cursors within the labview application were used to integrate the peak to find the area under the curve.

Results

The data was collected and resulted in various intensity vs. angular position plots, as can be found in Appendix A.1. The recurring pattern was a strong peak around 20°, and a second peak around 70°.

The peak wavelength λ_{peak} can be found by the following equation as a function of angle, in nanometres.

$$\lambda(\theta) = \sqrt{\frac{13900}{\sqrt{\left(\frac{2}{\sqrt{3}} \cdot \sin\theta + \frac{1}{2}\right)^2 + \frac{3}{4}} - 1.689}} \tag{1}$$

where $\theta = \theta_{init} - \theta_{peak}$, θ_{init} is the initial angle $\approx 75.7°$, and θ_{peak} is the angle of the radiation peak as determined by the data.

Similarly, the temperature T is determined by the equation

$$T = 300\text{K} + \frac{\frac{V}{IR_0} - 1}{\alpha_0} \tag{2}$$

where V is the potential in volts, I is the corresponding current in amperes, $R_0 \approx 1.1\Omega$ is the bulb resistance at room temperature, $\alpha_0 = 4.5 \times 10^{-3}\text{K}^{-1}$ is the thermal coefficient of the tungsten filament of this experiment's blackbody.

Using the angle and potential/current data from the collected data, the resulting calculation of $\lambda_{peak} \cdot T$ is as follows, where λ_{peak} is the peak wavelength, in m, and T is the temperature of the radiation source, in K.

V (V)	$\lambda_{peak} \cdot T$ (10^{-3}mK)	σ ($\pm 10^{-5}$mK)
4.0	1.702	5
4.5	2.093	5
5.0	1.753	4
5.5	1.974	4
6.0	2.189	4
6.5	2.278	4
7.0	2.214	4
7.5	2.345	3
8.0	2.249	3
8.5	2.428	3
9.0	2.406	3
9.5	2.400	3
10.0	2.239	3

Table 1: Results for Wien's Law calculations

The desired result is as calculated by Wien's displacement Law, $\lambda_{peak}T = 2.898 \times 10^{-3}$m·K. Since none of these values fall within one standard deviation of the expected result, this data cannot be said to be accurate.

Using the equation

$$\frac{P}{A} = \sigma T^4 \tag{3}$$

as determined by Stefan and Boltzmann, where $\frac{P}{A}$ is the emitted power per unit area, σ is the Stefan-Boltzmann constant, and T is the temperature, a comparison can be made between the expected function of power per unit area and the integration of the intensity as a function of angular position, where the latter is rather a proportional similarity rather than a strict equal. Using a constant of proportionality to compare the two sets results in the following plots of $\frac{P}{A}$ vs T^4.

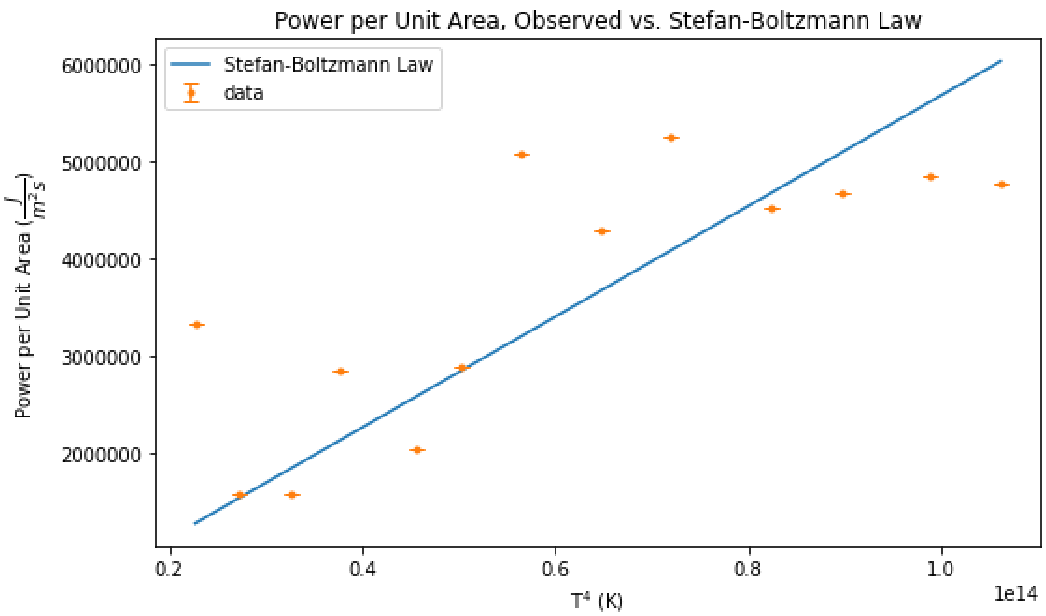

Figure 1: Comparing the integration of intensity data to the Stefan-Boltzmann Law

As can be noted, the already small uncertainties become irrelevant in this scale, since the power per unit area is proportional to T^4. The data does suggest a positive correlation, although the strength of a linear fit is not high.

Discussion

While performing the experiment, adjustments were made in order to improve results. The collimating slits were not used, as they dimmed the light source to a degree that made it difficult for the light sensor to scan. Additionally, all scans were done over 80 degrees, as opposed to the 30 degree option. When a scan was done over 30 degrees, the resulting graph failed to include all important aspects of the emitted spectrum. This change does not affect any of the results, as it merely increased the size of available data.

The experiment proved to be somewhat of a challenge, and not in the traditional sense; difficulties were had when first attempting to gather data using the given guidelines. The main issue was in the labview application's plot, in that we were failing to observe the expected main peak followed by a smaller blip behavior. Instead, the plot featured no additional blip and an overall continual increase. After the above adjustments were made, the experiment gave the expected results.

Questions

1. As the temperature of the bulb increased, no distinguishable change in color was observed. As for the spectrum, the violet color seemed to progressively dominate the spectrum as temperature increased. For the filament, the color is red at lower temperatures and white at high temperatures. This is because as temperature increases, the peak wavelength decreases. At lower temps, the peak wavelength falls on (or near) the redder side of the visible light spectrum. And at higher temps, the peak wavelength is shorter and will fall closer to the violet side of the spectrum.

2. For the highest temperature, more of the intensity is in the infrared part of the spectrum. For the lowest temperature, the peak falls in the infrared, as does much of the intensity. In comparison, the highest temp covers more of the visible light spectrum than the lowest temp. If the bulb could reach even higher temperatures, it would be more efficient at producing visible light, however, the filament material would have to be able to endure such high temperatures while remaining as a solid.

Conclusion

An ideal blackbody can be approximated by an incandescent light bulb and a prism spectrophotometer, producing an intensity pattern which can be measured using a rotating frame sensor and analyzed using Wien's Law, as well as the Stefan-Boltzmann Law, in conjunction with numerous other relationships between a blackbody's peak wavelength and temperature.

Appendix

A Plots

A.1 Intensity vs Angular Position

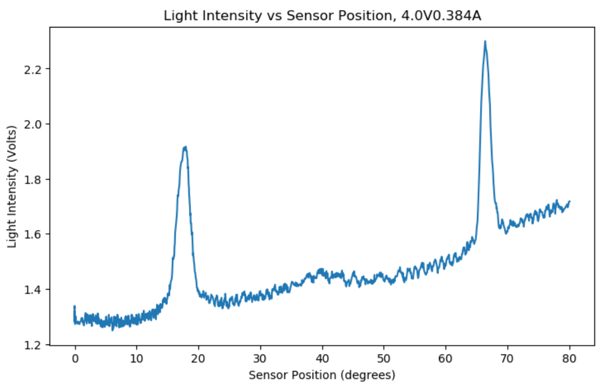

Figure 2: 4.0V, 0.384A

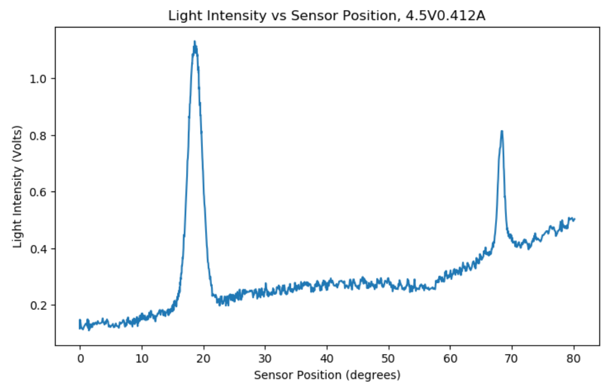

Figure 3: 4.5V, 0.412A

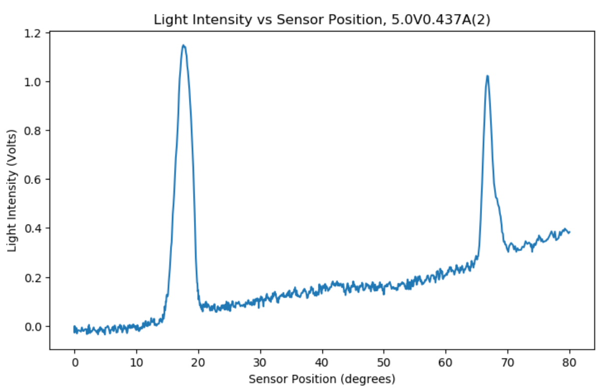

Figure 4: 5.0V, 0.437A

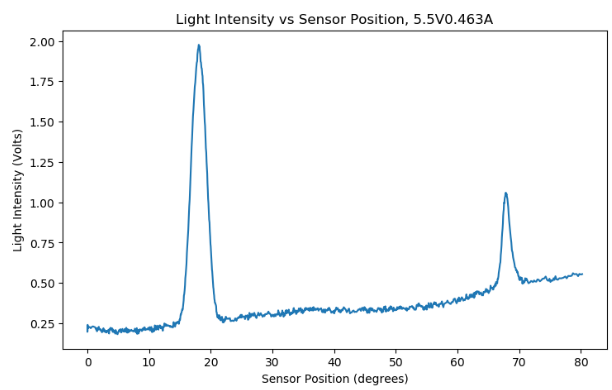

Figure 5: 5.5V, 0.463A

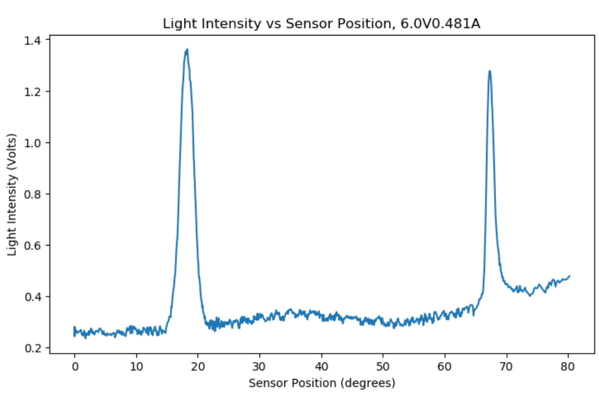

Figure 6: 6.0V, 0.481A

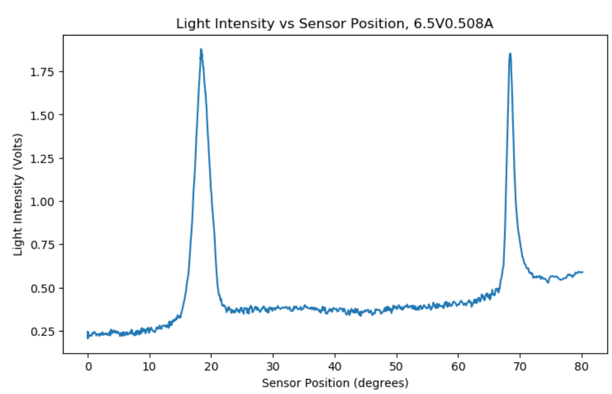

Figure 7: 6.5V, 0.508A

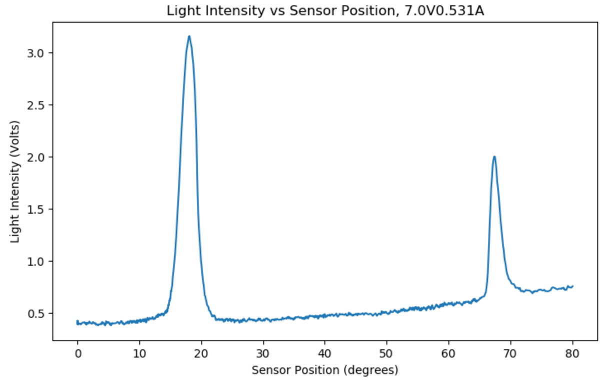

Figure 8: 7.0V, 0.531A

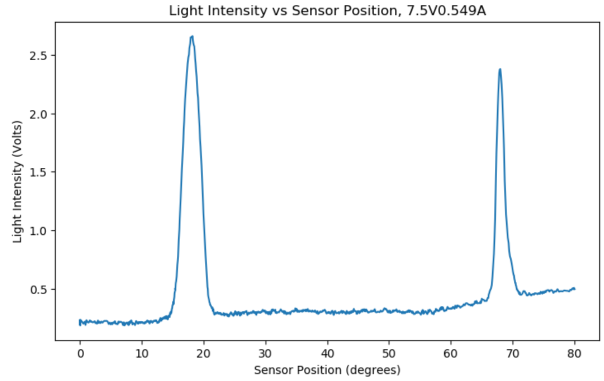

Figure 9: 7.5V, 0.549A

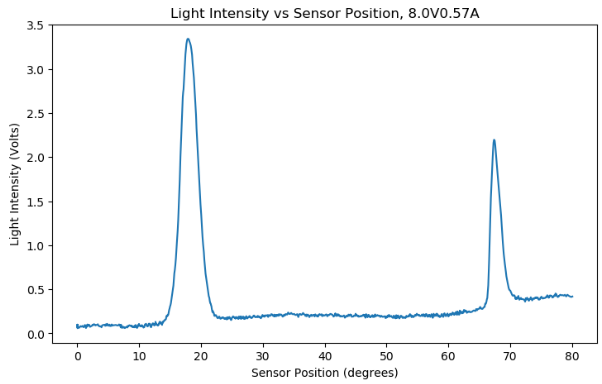

Figure 10: 8.0V, 0.570A

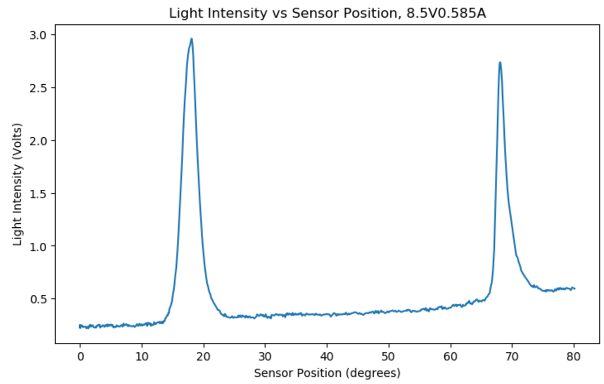

Figure 11: 8.5V, 0.585A

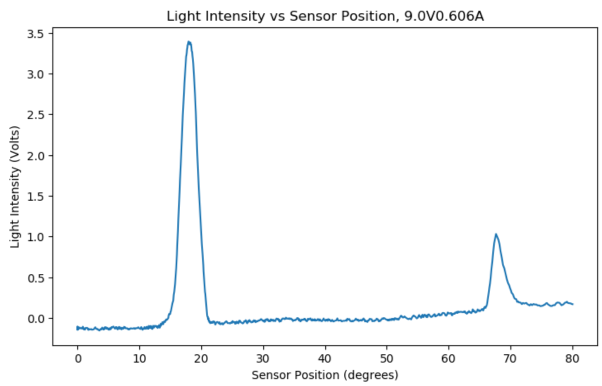

Figure 12: 9.0V, 0.606A

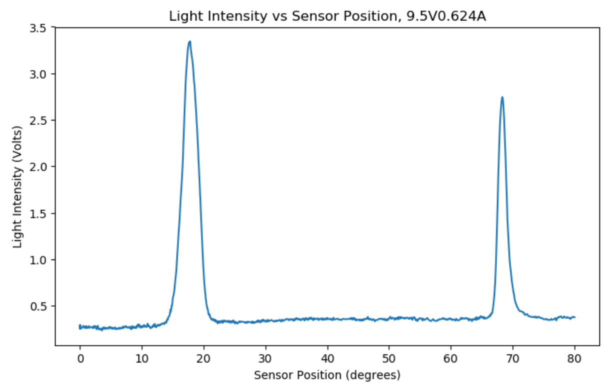

Figure 13: 9.5V, 0.624A