

Blackbody Radiation

EQUIPMENT

INCLUDED:

1	Prism Spectrophotometer Kit	OS-8544
1	Optics Bench (60 cm)	OS-8541
1	Spectrophotometer Accessory Kit	OS-8537
1	Aperture Bracket	OS-8534
1	Broad Spectrum Light Sensor	CI-6630
1	Rotary Motion Sensor	CI-6538
1	Voltage Sensor	CI-6503
1	Power Amplifier II	CI-6552A
1	Replacement Bulb (10 pk)	SE-8509
1	Banana Plug Cord-Black (5 pack)	SE-9751

NOT INCLUDED, BUT REQUIRED:

1	ScienceWorkshop 750 Interface	CI-7650
1	DataStudio	CI-6870

INTRODUCTION

The spectrum of an incandescent light bulb is scanned by hand using a prism spectrophotometer that measures relative light intensity as a function of angle. A Broad Spectrum Light Sensor is used with a prism so the entire spectrum from approximately 400 nm to 2500 nm can be scanned without the overlapping orders caused by a grating. The wavelengths corresponding to the angles are calculated using the equations for a prism spectrophotometer. The relative light intensity can then be plotted as a function of wavelength as the spectrum is scanned, resulting in the characteristic blackbody curve. The intensity of the light bulb is reduced, reducing the temperature, and the scan is repeated to show how the curves nest with a shift in the peak wavelength.

The temperature of the filament of the bulb can be estimated indirectly by determining the resistance of the bulb from the measured voltage and current. From the temperature, the theoretical peak wavelength can be calculated and compared to the measured peak wavelength.

THEORY

The intensity (I) of radiation emitted by a body is given by Planck's Radiation Law:

$$I(\lambda) = \frac{2\pi^5 c^2 h}{15} \frac{1}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1} \quad (1)$$

where c is the speed of light in a vacuum, h is Planck's constant, k is Boltzmann's constant, T is the absolute temperature of the body, and λ is the wavelength of the radiation.

The wavelength with the greatest intensity is given by

$$I_{\max} = \frac{\text{constant}}{T} = \frac{0.002898m \cdot K}{T} \quad (2)$$

where T is the absolute temperature of the body. The temperature of the blackbody light filament can be calculated using the resistance of the filament while it is lit. The resistivity of the tungsten filament is a nonlinear function of the temperature. A function that approximates the calibration curve (CRC Handbook, 45th edition, page E-110) for the resistivity of tungsten is used in the DataStudio setup file to calculate the temperature.

The resistance of the filament is found using

$$R = \frac{V}{I}$$

where V is the voltage applied to the lamp and I is the current through the lamp.

SET UP

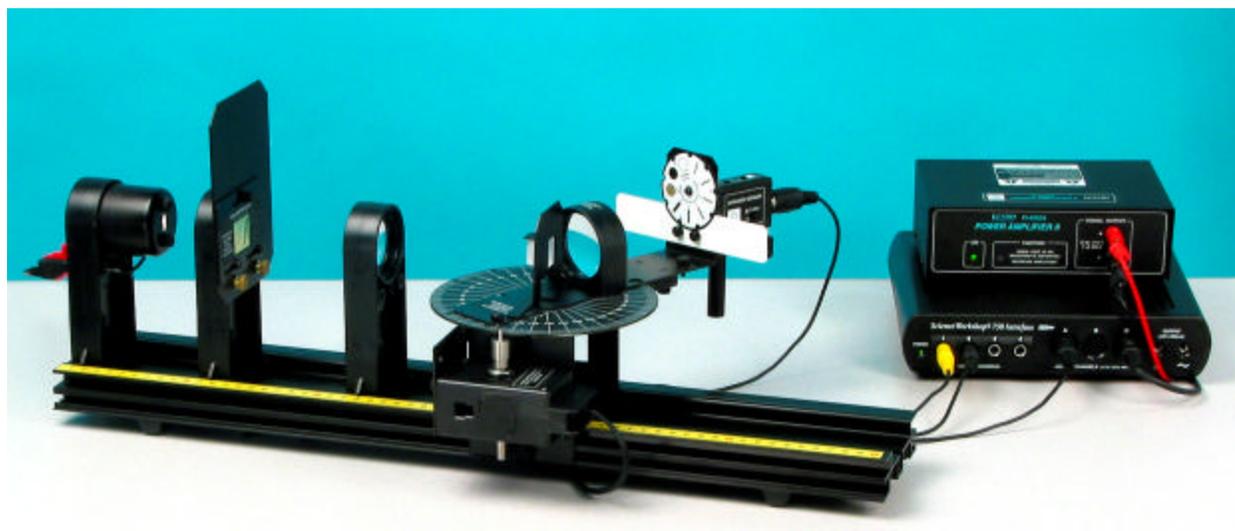


Figure 1: Complete Setup

1. Set up the Prism Spectrophotometer as shown in Figure 1. Attach a grounding wire to the spectrophotometer table as instructed by your teacher. The light sensor used in this experiment is the Broad Spectrum Light Sensor.
2. Check that the prism is oriented as shown in Figure 2 with the apex facing the light source.
3. The collimating lens must be 10 cm from the collimating slits.
4. Plug the Blackbody Light into the Power

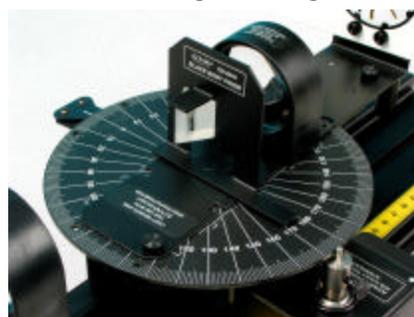


Figure 2: Prism Orientation

Amplifier. Plug the Power Amplifier into Channel C of the ScienceWorkshop 750 interface.

5. Plug the Broad Spectrum Light Sensor into Channel A of the interface. Plug the Voltage Sensor into Channel B. Connect the leads of the Voltage Sensor to the Blackbody Light. Plug the Rotary Motion Sensor into Channels 1 and 2.
6. Open the DataStudio setup file called "Blackbody".

PROCEDURE

1. Set the collimating slits on Slit #4. Set the Light Sensor mask on Slit #4.
2. In DataStudio, click the Signal Generator window and turn the generator ON at 10 V DC. **Caution:** If 10 volts is applied to the blackbody light for an extended amount of time, the life of the bulb will be reduced. Only turn the bulb on when taking measurements.
3. Look at the light coming from the Blackbody Light Source. Observe the color.
4. Look at the spectrum on the Light Sensor screen. Are all the colors (from red to violet) present?

5. Rotate the scanning arm until it touches the stop. This will be the starting position for all the scans.
6. Set the Broad Spectrum Light Sensor gain switch to "x100" and press the tare button. Click START in DataStudio.
7. As the scan begins, check that the angle is positive. If not, reverse the Rotary Motion Sensor plugs in the interface and re-start the data run. Slowly rotate the scanning arm through the spectrum and continue all the way past zero degrees (the position where the light sensor is directly opposite the light source). The graph of intensity vs. wavelength will stop at about 2500 nm because the glass in the spectrophotometer optics does not transmit wavelengths greater than 2500 nm.
8. There will be a peak on the intensity vs. angle graph where the light sensor is aligned with the light source because some light passes by the prism instead of going through the prism. This peak enables the initial angle to be exactly determined. Use the Smart Cursor to determine the angle from the starting position to the central peak where the light sensor is directly opposite the light source. Click the calculator in DataStudio and enter this angle called "init".

Figure 3: Spectrum on Light Sensor Mask

9. Repeat Steps 2 through 7 for voltages of 7 V and 4 V. On these scans, it is not necessary to scan all the way past the center as before because the angle has already been calibrated.

ANALYSIS

1. Does the peak shift toward shorter or longer wavelengths as the temperature is lowered?
2. How does the intensity change as the temperature is changed?
3. Use the Smart Cursor on the Temperature graph to find the temperatures of the filament. Calculate the peak wavelength for each temperature using Equation (2). Do these theoretical values correspond to peak wavelengths on the intensity graphs?
4. Planck's formula (Equation (1)) is already in the DataStudio setup file. Click and drag the calculation from the Data List on the left to the graph of intensity vs. wavelength. Change the amplitude in the calculator so it matches the tallest curve. Does the shape of the curve match the theoretical curve? Can the bulb really be considered a blackbody?
5. How did the color of the bulb change with temperature? How did the color composition of the spectrum change with temperature? Considering the peak wavelengths, why is a bulb's filament red at low temperatures and white at high temperatures?
6. At about what wavelength is the peak wavelength of our Sun? What color is our Sun? Why?
7. For the highest temperature, is more of the intensity (area of the intensity vs. wavelength graph) in the visible part of the spectrum or in the infrared part of the spectrum? How could a light bulb be made more efficient so it puts out more light in the visible?