

The Herschel Experiment

•Materials

One glass prism
 3 alcohol thermometers with blackened bulbs
 scissors
 cardboard box
 blank piece of white paper

•Introduction

Herschel discovered the existence of infrared light by passing sunlight through a glass prism in an experiment similar to the one you'll do here. As sunlight passed through the prism, it was dispersed into a rainbow of colors, a spectrum. Herschel was interested in measuring the amount of heat in each color and used thermometers with blackened bulbs to measure the various color temperatures. He noticed that the temperature increased from the blue to the red part of the visible spectrum. He then placed a thermometer just beyond the red part of the spectrum in a region where there was no visible light and found that the temperature was even higher. Herschel realized that there must be another type of light beyond the red, which we cannot see. This type of light became known as *infrared*. *Infra* is derived from the Latin work for "below". In this lab, you will complete an experiment very similar to Herschel's original one.

•Predictions

Before starting the experiment, make some predictions about what will happen. Write answers to the following questions on a piece of paper that you will hand in with your lab. It's okay if you don't know the answer right now, but put down your ideas anyway. In what region will you observe the highest temperature? Why? What color is the sun? Why do we see in "visible"? What kind of light is more energetic, red light or blue?

•Procedure

This experiment should be conducted outdoors on a sunny day.

1) Place the piece of white paper on the bottom of the cardboard box.

2) Carefully attach the glass prism near the top, sun-facing edge of the box. Do this by cutting out an area from the top edge of the box that the prism will fit snugly into.

3) Place the prism in the slot you created and rotate it so it creates the widest possible spectrum on the **shaded portion** of the white sheet of paper at the bottom of the box. You can elevate the sun facing side of the box to create a wider spectrum.

4) Now, place the three thermometers in the shade and record the temperature each reads.

5) Next, place the thermometers in the spectrum such that one of the bulbs is in the green region, another in the orange region, and the third just beyond the red region. If you can't get this to work out perfectly, that's okay, just make sure to record what region each of your bulbs was in during the time you took your measurements.

6) It will take 3 minutes or so for the thermometers to record the final values. Do not move the thermometers from the spectrum or block the spectrum while reading the temperatures.

7) Record all of your measurements on a piece of paper that you will turn in with the rest of your lab. You should record the temperature of each thermometer after each of the three minutes.

8) Repeat steps 4-7 two more times.

9) Calculate an average final temperature for each region and record. Compare your averages with the other lab teams.

•Questions

Answer the following questions on a separate piece of paper. **For credit, turn your answers, your predictions, and your recorded data.**

1) What color/region did you find to have the highest temperature? Did you measure infrared light? Did you record different values during different runs?

2) Does it make sense to you what region had the peak temperature? In what color do you think the sun emits the most energy?

3) Look at the following diagrams and corresponding discussions, then re-analyze your answer to question 2.

4) Answer all questions posed in the discussion.

List of visible wavelength ranges, for reference.

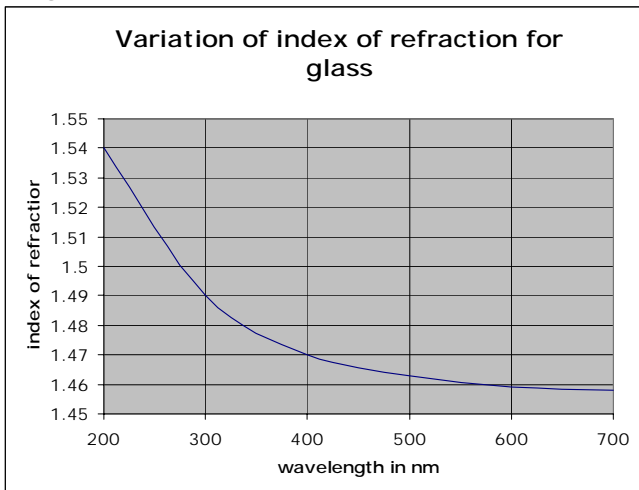
Red	620-700nm
Orange	590-620
Yellow	570-590
Green	490-570
Blue	440-490
Violet	390-440

There are 10^9 nanometers (nm) in a meter.

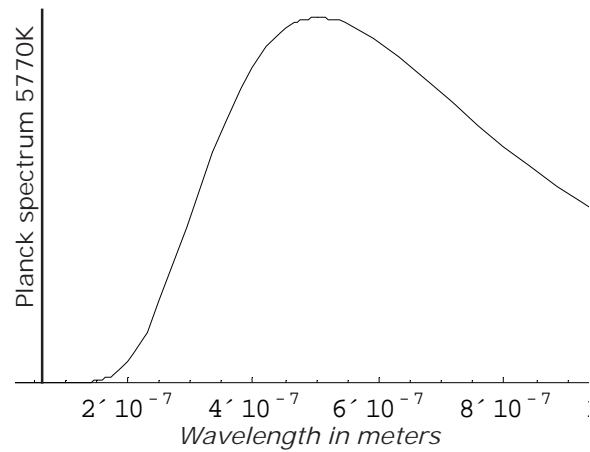
To change a wavelength into a frequency, use the formula

$$f = \frac{c}{\lambda}$$

where f is frequency in Hz and λ is wavelength in meters.



The graph above is plot of how the index of refraction varies with wavelength in glass. There are actually many types of glass, and each has a somewhat different index of refraction. This one is for silica. If the plot were a straight line, "linear", we would have equal spacing of wavelengths when light is refracted through a prism. However, the plot is not a line, but a curve which flattens out toward the red end of the spectrum. Due to the fact that the index of refraction changes very little at the red end of the plot, the wavelengths there will be bunched up, more concentrated.



You should recognize this plot as a Planck or blackbody spectrum. The radiated light from the sun can be approximated by a blackbody at 5770K. Use Wien's Law to find the peak wavelength of the Sun's emission.

Wien's Law:

$$\lambda_{\text{max}} = \frac{2.9 \times 10^6}{T}$$

Where λ_{max} is the peak wavelength of the Planck spectrum in nanometers and T is temperature in Kelvin.

Is this the wavelength you expected? To obtain an energy from the Planck spectrum, integrate over a wavelength range. If you are unfamiliar with the concept of integration, you can think of it here as the area under the curve from one spot on the x axis to another. For example, you can see by simply looking at the plot that the area under the curve between 200 and 300 nm is less than the area between 500 and 600 nm. Using this type of estimation, in which color does the sun emit the most energy? The difference between energy emitted from the sun in green and red is not great, but in a well done, *corrected* experiment, is measurable.

You might now be asking yourself a logical question. If the sun emits the most in green, why does it appear yellow? In fact, it is an *appearance*. The sun is actually white, but against the blue sky, it looks yellow. **Caution: never look directly at the sun** - it can burn your eyes in a matter of only a fraction of a second. Astronauts in space observe the sun as white, due to the black rather than blue background they see it against. To prove this to yourself, try the following experiment on your own time.

Experiment:

Gather two pieces of blue paper and a small square of white paper. Attach the white square to the middle of one of the sheets of blue paper. Stare at the empty blue page for about 30 seconds, then place the other on top. What color do you observe the white paper to be? Most see the white chunk as yellowish!

It is a common misconception that the sun is yellow. In fact, most astronomy text books simply classify the Sun as a G2 "yellow" star and don't explain the difference between the spectral classification and the true "color" of the Sun or other stars. Of course, we could spend quite a bit of time discussing what exactly *color* is, and how our eyes see color, but that is left to you. The following website is helpful if you're interested:

<http://casa.colorado.edu/~ajsh/colour/Tspectrum.html>

5) Summarize what your Herschel experiment results were, why you got those results, and state what you should have observed if you corrected for the non-linear nature of the index of refraction of glass.

•Further investigation (for extra credit)

The formula for Planck function is

$$B_{\lambda}(T) = (2hc^2/\lambda^5)(\exp(hc/\lambda kT)-1)^{-1}$$

Where

- h = Planck's constant
= 6.626×10^{-34} J*s
- c = speed of light
= 3×10^8 m/s
- k = Boltzman's constant
= 1.38×10^{-23} J/K

Use $T = 5770\text{K}$ for the temperature of the Sun.

Using Mathematica or some other math tool, plot the function. Then numerically integrate over a few wavelength ranges to obtain the energy emitted in that range. What percent of visible light energy is green? Red?