Collecting a Spectral Reflectance Curve

An Exploration of the Electromagnetic Spectrum beyond Human Visibility

In this activity, your group will explore:

- The Electromagnetic Spectrum
- Different Types of Radiation
- Spectral Reflectance Curves

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# Collecting a Spectral Reflectance Curve

**Exercise:** An Exploration of the Electromagnetic Spectrum beyond Human Visibility

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## Summary of skills covered:
- The Electromagnetic Spectrum
- Different Types of Radiation
- Spectral Reflectance Curves
- The Effect of Material Composition (Vegetation) on the EMS
- Using a spectrometer
- Collecting data
- Graphing results

## Data needed:
Students will collect and graph their own data using a spectrometer.

## Equipment and Software needed:
**Hardware:** Spectrometer (A spectrometer kit is available from VirginiaView / the Virginia Geospatial Extension Program). Contact John McGee (jmcg@vt.edu) or Jim Campbell (Jayhawk@vt.edu) for details.

**Software:** None

## Related book exercise (if applicable):
No text necessary.

## Data Source:
Not applicable
Objective

During this activity you will collect, manipulate, and graph data to understand the properties of light. You will also gain an understanding of the electromagnetic spectrum and reflectance of light by creating your own spectra from your data, and graphing it on the handouts that are provided.

The Electromagnetic Spectrum

![The Electromagnetic Spectrum](Figure 1: The electromagnetic spectrum. Courtesy: http://mynasadata.larc.nasa.gov/)

Introduction

X-rays, thermal radiation, microwaves, radio waves, and gamma radiation all travel through space at the speed of light. They interact with matter both electrically and magnetically, and together are called electromagnetic radiation. By sensing electromagnetic radiation we can see the world around us. When you listen to the radio in your car, the songs you hear (or at least the signal your radio uses to vibrate the speakers) are also the result of electromagnetic radiation moving from the antenna at the radio station to the antenna on your car. Different kinds of electromagnetic radiation differ in wavelength and this results in a spectrum. The visible spectrum (the colors that humans can ‘see’) is only a small portion of the larger electromagnetic spectrum (Figure 1). The electromagnetic spectrum is divided into major types of radiation which include:

- Radio waves (including microwaves)
Infrared
Visible light
Ultraviolet
X-Rays
Gamma and Cosmic rays

The only part of the electromagnetic spectrum that humans can see is the visible light spectrum, and every other part of the electromagnetic spectrum is only visible with the aid of special equipment. You will use a piece of such special equipment today to measure wavelengths of light that your eyes cannot see. Our eyes make measurements of the amount of radiation reflected from objects around us, with our brains translating these measurements into an image of our surroundings. However, our eyes are only sensitive toward the areas between the red and purple ends of the visible spectrum. As a result of this, other wavelengths of light, including the infrared and ultraviolet portions of the spectrum, are invisible to the human eye. However, the Sun radiates radiation across the entire spectrum, and as a result, although we cannot see it, all of the objects around us interact with this invisible radiation. By designing sensors that are sensitive to these wavelengths of light we can use artificial “eyes” to study these interactions.

Each type of electromagnetic radiation has its own unique wavelength and moves through space as a wave. The wavelength of electromagnetic radiation is the distance from one crest of a wave to the next wave crest (or one trough to the next trough: Figure 2). These types of waves can also be described by their frequency. The frequency of a wave is the number of whole waves or cycles that pass by a given point in a certain amount of time (see Figure 1).

When visible light radiation hits an object, some of it reflects off the object and into our eyes. Not all of the light will be reflected off the object as some of it may be absorbed or even transmitted through the object itself. The way that light is absorbed by an object usually determines what the color looks like, and is determined largely by the chemistry of the surface (that is, the atoms and molecules that make up an object). If an object (such as a blank sheet of paper) does not absorb any light, then it appears white, because it reflects all wavelengths equally. If all of the light that hits an object is absorbed, then no light will be reflected off of it and it will appear to be black.

Most of the time, only certain wavelengths of visible light are absorbed. A good example of this is a green leaf. Leaves usually absorb wavelengths that correspond to blue, yellow, orange, and red light. This is because the chemical chlorophyll present in most healthy leaves absorbs these wavelengths of light and converts the energy into food for the plant. The green color of leaves is not directly from the chlorophyll; it is because chlorophyll reflects green wavelengths, and this is what we “see”. Thus, the chlorophyll in the leaf absorbs certain parts of visible light energy, and converts it to the chemical energy of sugars by the process known as photosynthesis. Chlorophyll absorbs and uses both blue and
red light to make sugars. Leaves also contain other pigments which can give them other colors depending on the amount of pigment present:

- carotenes and xanthophylls give leaves their red, yellow, and orange color
- flavonoids cause leaves to have pink to purple colors

These differences in absorption and reflectance of different colors of light give us important clues to understanding and interpreting the world around us. Thus, these colors, which are observed from a satellite image or airplane, aid scientists in determining the ripeness of crops, health of forests, origin of pollutants, and many more applications. These sensors can provide vital information that is used by an array of everyday business needs.

In this activity, you will obtain reflectance data for a green leaf, standardize the results against a white poster board, and perform data analysis. Although it may not seem like it, the process you will use is very similar to that used by scientists who use Earth observation satellites, such as Landsat, to study Earth’s surface from space. Landsat is the world’s longest-running moderate resolution satellite series. Since 1972, one or more Landsat satellites have been observing the Earth’s surface. Like the ALTA II Spectrometer, the Landsat satellites record the electromagnetic radiation reflected from Earth in various portions of the spectrum. This information is then sent back to Earth as satellite images and is used by experts in many different fields, including agriculture, forestry, and regional planning.

Farmers, for example, use Landsat satellite imagery to identify specific areas of their fields where crops are stressed. Using the near infrared and other wavelengths, they can identify crops with insect infestations, irrigation needs, disease, or differences in soil fertility. Vegetation stress in crops can often be discovered and mitigated long before it is evident to the human eye--and by the time humans see the damage, the situation is often too late to correct. Firefighters use Landsat images to identify ‘hot spots’ (using the thermal wavelengths) to coordinate firefighting efforts during a large forest fire event. Urban planners can compare Landsat images over time to identify growth areas of a city using an array of wavelengths. The use of satellite imagery, such as Landsat, is invaluable to our economy.

Feel free to explore additional information about the Landsat program here: [http://landsat.gsfc.nasa.gov/education/](http://landsat.gsfc.nasa.gov/education/).

**Materials**

1. ALTA II reflectance spectrometer
2. Green leaves, larger than 2” square
3. White poster board or thick white paper, in pieces approximately 3” x 5” or larger
4. Calculator (optional)
5. Data tables from template
6. Activity Handouts
The ALTA II Spectrometer

The ALTA reflectance spectrometer works very similar to a sensor aboard a Landsat satellite. The spectrometer is like a mechanical eye. When you go outdoors on a sunny day and look at a leaf, it appears green to you because, as mentioned on the last page, the molecules that make up the leaf absorb red and blue wavelengths of light, but reflect the green wavelengths to your eye. In this case, the source of the light is the sun, shining on the leaf. If you looked at the same leaf in the middle of the night it would not look green to you, unless you took a flashlight with you. The ALTA spectrometer uses something like a flashlight to illuminate an object you want to study, before using a sensor (a bit like your eye) to measure the amount of light that the object reflects.

If you look at the back of the spectrometer you will see a ring of small lamps. These are the source of the light you will measure. The larger object in the middle of the ring of lamps is the sensor, or detector. Like your eye, the detector measures the amount of light that any object placed beneath the spectrometer reflects. If you place an object beneath the spectrometer and push the blue button, the spectrometer will shine blue light (that is light with a wavelength of about 470 nanometers, nm, where a nanometer is a billionth of a meter) onto the object, and the sensor will at the same time measure how much of that light is reflected. If you push the red button, the spectrometer will shine red light onto the object and measure the amount of red light (645 nm) that is reflected. You will notice that the lower four buttons are not colored. Pressing one of these buttons will cause the ALTA to shine infrared light onto the object. This light is invisible to our eyes. By pressing these buttons you will be able to measure how much infrared light an object reflects – you will be able to measure invisible light!

In the real world objects can look very different in the infrared to how they look in the visible parts of the spectrum. For example, at visible wavelengths snow and clouds look very similar – they both reflect lots of light at all visible wavelengths and hence look white to us. But in the infrared part of the spectrum snow reflects very little light (and appears dark) whereas clouds reflect a lot of radiation (and appear bright). Because different objects on Earth’s surface reflect different amounts of light at different wavelengths, scientists and engineers have
designed, built, and launched satellites to make similar measurements from space. Although the sensors that these satellites use to make these measurements are more complex and expensive than the ALTA II spectrometer, they in fact work in a similar way, exploiting much the same physics principles. After you finish this exercise, the next time you see a satellite image on the television weather report, you will be able to say, “I know how the satellite collected that image!”

**Procedure**

1. Turn the spectrometer “on”. Place the spectrometer, lamp side down, on a green leaf so that the lamp and sensor array are over the leaf. Note the display number (given in millivolts) when you are not pressing any buttons on the color switch pad and no ALTA lamps are on (Figures 4 and 5). Record this on Table 1 as the “Dark voltage.” Now, start with the blue lamp, and turn it on by pushing the blue switch pad button on the ALTA face while continually holding it down. The display number will change from its “dark” value. Initially it will vary a lot, but within a few seconds it will settle down and stop changing so much (this is why you need to hold the button down). There may be some variations in the last couple of digits, but when the display number is fairly constant, record it on the reflectance calculation worksheet in the “Blue” row and “Sample” column. Using the same procedure, work through the rest of the lamp colors on the ALTA, recording all measurements on the data sheet (e.g. cyan lamp, green lamp, yellow lamp, all the way through IR4 lamp).

2. Graph your raw results on the handout “Graph 2: Spectrometer Voltage vs. Color”, where the number you read from the ALTA display goes on the Y axis. Label the curve you produce “Leaf”.

3. Now, ask your fellow students what their display numbers were for green and infrared-3 (IR3). There will be a lot of variation, even though the leaves should be similar, and everyone is using the same spectrometers. The problem is that even if you all looked at the same leaf, the measurements you made using different spectrometers will all be slightly different because you are all using different spectrometers. It is the same when scientists make measurements from space, and scientists and engineers go to great lengths to make sure measurements made from different satellites can be directly compared with each other. This is especially important when using satellites to study Earth’s climate: scientists want to be sure that the changes they observe in, for example, sea surface temperatures recorded over a 30 year period, are real, and not just because they have been made using different sensors on different satellites.

To correct for these differences between instruments and to allow you to more directly compare you results with those of your classmates, measurements of the amount of light reflected by the leaf can be given as the percentage (or proportion) of light reflected by the leaf at each wavelength. One way to measure how much light hits the leaf and how much is...
reflected is to take reflectance measurements of a standard material, and then compare the amount of light the leaf reflected to the amount that the standard reflected. A standard material is something for which we know (or at least reliably assume) how much light is reflected. Good standards for this experiment are heavy white paper or white poster board, which reflect almost all of the light that hits them. Satellites in Earth orbit also use similar “white standards” although the material used is much more expensive than white poster board. White photocopy paper or notebook paper is OK but not the best. This is because it is thinner than white poster board, and allows some light to pass through it.

To measure the reflectance standard, put the spectrometer on the white card and measure the output voltage for each lamp (Figure 4), in the same way you did for the leaf. Write these numbers in the worksheet in the column labeled “Standard White Paper” which can be seen in Figure 6. You’ll notice that while the light measured from the leaf varies a lot with color (with wavelength) the white standard varies much less. A perfect white standard would not vary at all, but your card is a good, and cheap, alternative (scientists use a white material called “Spectralon” which costs about $350 for a piece the size of a quarter).

Graph your results on “Graph 2: Spectrometer Voltage vs. Color” and label the curve you produce “White standard”. Compare it with your leaf curve.
4. With the “Standard White Paper” data, you can now calculate the percentage of light reflected by the leaf. For each color, divide the display voltage number for the leaf (minus the dark voltage) by the display voltage number for the white paper (minus the dark voltage), then multiply by 100. Record the value on the worksheet (Figure 5). This value is called the percent reflectance as shown below.

\[
\text{% Reflectance} = \frac{(\text{sample voltage} - \text{dark voltage})}{(\text{standard voltage} - \text{dark voltage})} \times 100
\]

5. Using your results, graph your % Reflectance on the “Percent Reflectance vs. Color” graph. If you were to plot the white card as a standardized reflectance in the same way, you would find that at every color the reflectance would be 100%. Compare this to the “Standard White Paper” curve you plotted on Graph 2. Here the Spectrometer voltage varied with color. This is the purpose of relating the raw spectrometer values for your sample (the leaf) to the white standard; it removes reflectance variations caused by differences in the spectrometers, to leave only those color variations that are due to the chemical properties of the sample.

You have now calculated a reflectance spectrum for a green leaf. You can calculate the reflectance spectrum for other objects (asphalt, pavement, dirt, leaf litter) and compare the results.

In addition to measuring observations on the surface of the earth in the blue, green, red, and near infrared wavelengths (like the Alta II), the Landsat satellite can also record observations in other wavelengths as well. For example, the Landsat satellite can record thermal data as well. Using thermal wavelengths, Landsat sensors are able to assess and map heat differences on the earth’s surface. How might this be helpful to scientists? How could you collect this information?

**Additional Information and Exercises**

- **Introduction to the Electromagnetic Spectrum** (NASA), [http://missionscience.nasa.gov/ems/01_intro.html](http://missionscience.nasa.gov/ems/01_intro.html)
  
  This website provides in-depth information about the electromagnetic spectrum, radiative physics, and Earth’s radiation budget.

  
  This exercise gives students the chance to learn more about Landsat and explore how different types of radiation affect our ability to interpret the Earth.
STUDENT WORKSHEET: TAKING A REFLECTANCE SPECTRUM

Name: _____________________________________  Date: _________________
Partner(s): __________________________________  Period: _______________

Questions: After you have finished the experiment, please answer the following questions below in the space provided or on additional paper as needed.

1. List the five major types of radiation discussed in the experiment.

2. Why can humans only see the visible spectrum and not the entire electromagnetic spectrum?

3. List the three ways that light interacts with an object. (Hint: Refer to the introduction).

4. What substance in leaves absorbs specific colors of light to create energy?

5. What does the plant do with the energy that is created by the light it absorbs, and what is the name of the process described in the previous question?
1. Besides chlorophyll, give two other examples of other pigments that are found in leaves.

2. Why was the poster board used as a standard material instead of regular printer paper?

3. Read the display numbers for the various spectra (plural of spectrum, where a spectrum is the curve you plotted) on Table 1. How does the value differ for infrared light compare to the blue?

4. Compare the reflectance spectrum for your sample leaf to the reflectance spectrum for spinach that has been provided in Graph 1. How does the shape of your spectrum compare to the one for spinach?
Table 1: Calculating Reflectance

<table>
<thead>
<tr>
<th>Color</th>
<th>Light Wavelength</th>
<th>Sample: Standard White Paper:</th>
</tr>
</thead>
</table>
| Blue     | 470 nm           | \[
\frac{\text{Sample Voltage} - \text{Dark Voltage}}{\text{Standard Voltage} - \text{Dark Voltage}} \times 100
\]
| Cyan     | 525 nm           |                                |
| Green    | 560 nm           |                                |
| Yellow   | 585 nm           |                                |
| Orange   | 600 nm           |                                |
| Red      | 645 nm           |                                |
| Deep Red | 700 nm           |                                |
| Infrared 1 | 735 nm       |                                |
| Infrared 2 | 810 nm       |                                |
| Infrared 3 | 880 nm       |                                |
| Infrared 4 | 940 nm       |                                |
*Note: You will be using this graph to compare your reflectance results of the sample leaf to the reflectance of spinach. You will also need to use this graph to answer question 1.

**Note: Look at the x-axis. A nanometer is one billionth of a meter. To give you an idea just how small a unit of measurement this is, one nanometer is about 1000 times narrower than a human hair. Imagine taking a hair from your head and slicing it, lengthwise, into 1000 pieces. The wavelengths of light in this part of the spectrum (the distance between successive peaks or troughs of the electromagnetic wave) is very, very small indeed.
Graph 2: Spectrometer Voltage vs. Color
Graph 3: Percent Reflectance vs. Color

Wavelength (nanometers)

Percent Reflectance

Blue  Cyan  Green  Yellow  Orange  Red  Deep Red  IR1  IR2  IR3  IR4