ALTA® Reflectance Spectrometer

Introduction and Classroom Lessons

By Allan H. Treiman

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ALTA Reflectance Spectrometer Introduction and Classroom Lessons

This curriculum is designed to be used with middle school through introductory college level students. It covers basic experimental techniques and leads students to the investigation of concepts such as light, color, spectral analysis, environmental studies, and planetary science. Master copies of spectra data sheets and graphs are included.

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The ALTA® Reflectance Spectrometer and
classroom lesson plans are distributed by
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Brief Operating Instructions

1. *Battery.* The ALTA® uses a standard 9-volt battery, which is inserted in the slot on the bottom of the spectrometer. The battery should be removed before storing the ALTA®.
2. *On/Off.* The on/off switch is on the keypad of the ALTA® spectrometer. To turn the ALTA® on, press the switch. When the switch is turned on, the lamps in the bottom of the ALTA® will *not* turn on. However, the numerical display should show a number between 1 and 1999. If no number is visible, replace the battery. If there is still no number on the display, please call 281-486-2172 for servicing instructions.
3. *Color lamps and light detector.* Colored lamps are visible in the hole in the bottom face of the ALTA®. Each lamp is controlled by its own color-coded switch pad on the top face of the ALTA®. The light detector is centered among the colored lamps.
4. *Measuring reflectance.* With the ALTA® turned on, place it on the object to be measured so that the hole in the bottom is facing the object. Flat, matte-surface objects work best; *do not* let objects project into the hole. With no lamps illuminated, the display will show a number less than 150. This is the dark voltage. Press down, **and hold down**, a colored switch pad on the ALTA® top face to turn on a colored lamp. (Using the eraser end of a pencil to hold the switch pad down may be more comfortable.) The number in the display will become larger — this number (minus the dark voltage) is a linear measure of the amount of light that is striking the detector.
5. *Standards.* The amount of light represented by display numbers of the ALTA® is *not* calibrated. To calibrate this number, take reflectance measurements (as above) on an object with known reflectance values as a standard. A good standard is white poster board, which reflects about 85–90% of the light that hits it. A photographer's 18% gray card is an excellent real standard for the wavelengths here — from it, you can calculate the actual reflectance values for your white paper standard.

WARNING

The ALTA® spectrometer contains no user-serviceable parts. Its battery may be replaced by lifting up the door on the case bottom with a small screwdriver or letter opener. Under no circumstances should you open the spectrometer case. In case of malfunction, call 281-486-2172 for servicing instructions.

The ALTA® Reflectance Spectrometer is U.S. Patent #6043893. Allan Treiman, the Lunar and Planetary Institute, and the Universities Space Research Association assume no liability for damages that arise from the use of the ALTA® Reflectance Spectrometer.

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The Electromagnetic Spectrum

I. What is electromagnetic radiation and the electromagnetic spectrum?

What do light, X-rays, heat radiation, microwaves, radio waves, and gamma radiation have in common? Despite their differences, they are all the same kind of "stuff." They all travel through space and have similar electrical and magnetic effects on matter. This "stuff" is called electromagnetic radiation, because it travels (radiates) and has electrical and magnetic effects.

Electromagnetic radiation is the means for many of our interactions with the world: light allows us to see; radio waves give us TV and radio; microwaves are used in radar communications; X-rays allow glimpses of our internal organs; and gamma rays let us eavesdrop on exploding stars thousands of light-years away. Electromagnetic radiation is the messenger, or the signal from sender to receiver. The sender could be a TV station, a star, or the burner on a stove. The receiver could be a TV set, an eye, or an X-ray film. In each case, the sender gives off or reflects some kind of electromagnetic radiation.

All these different kinds of electromagnetic radiation actually differ only in a single property — their *wavelength*. When electromagnetic radiation is spread out according to its wavelength, the result is a spectrum, as seen in Fig. 1. The visible spectrum, as seen in a rainbow, is only a small part of the whole electromagnetic spectrum. The electromagnetic spectrum is divided into five major types of radiation. As shown in Fig. 1, these include radio waves (including microwaves), light (including ultraviolet, visible, and infrared), heat radiation, X-rays, gamma rays, and cosmic rays. Your eye can detect only part of the light

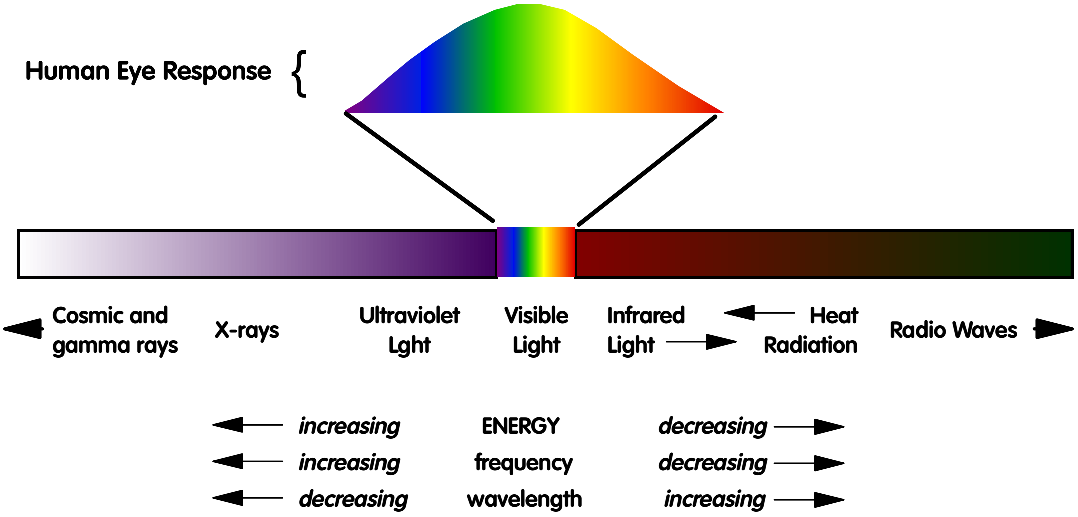


Fig. 1. The electromagnetic spectrum.

spectrum. Humans cannot sense any other part of the electromagnetic spectrum without the aid of special equipment. Other animals (such as bees) can see the ultraviolet while some (snakes) can see the infrared. In each case, the eye (or other sense organ) translates radiation (light) into information that we (or the bee looking for pollen or the snake looking for prey) can use.

Figure 1's "human eye response" is a magnified portion of the electromagnetic spectrum and represents the sensitivity of the average human eye to electromagnetic radiation. As this graph shows, the human eye is most sensitive to light in the middle part of the visible spectrum: green and yellow. This is why emergency vehicles are often painted garish yellows or green — they stand out in all weather, including fog, and at night better than the "old-fashioned" fire-truck red. The eye is much less sensitive toward the red and purple ends of visible light. The infrared and ultraviolet portions of the spectrum are invisible to humans.

Since the beginning of the modern age, mankind has expanded its ability to "see" into other parts of the electromagnetic spectrum. X-rays have proved useful for looking inside otherwise opaque objects such as the human body. Radio waves have allowed people to communicate over great distances through both voice and pictures. Today, increasingly clever uses of the spectrum allow us to see into the heart of a molecule (or person) while exploring Earth and space for the benefit of all.

2. Light and color

As shown in Fig. 1, each type of electromagnetic radiation has its own wavelength. But what length of what wave? Electromagnetic radiation moves through space (not just "outer space," but the atmosphere, buildings, lenses, etc.) as a wave, as wavelike changes in electrical and magnetic properties, similar to waves on the surface of water. The wavelength of electromagnetic radiation is the distance from the peak of a wave to the next peak, as shown in Fig. 2.

Electromagnetic waves can also be described by their frequency — that is, how many times a wave "waves" in a unit of time. For instance, imagine yourself as a ticket taker at a sports arena. Say 65 people pass your booth in 10 minutes. So, 6.5 people pass you per minute — the frequency of people passing is 6.5 people per minute. The frequency of an electromagnetic wave is exactly the same thing: the number of whole waves (or cycles) that pass by a point in some amount of time. Television and radio waves are usually described by their frequency; your favorite TV show might be on channel 8 in the VHF (very-high-frequency) band, or you might program your car's stereo to 92.8 Megahertz (millions of

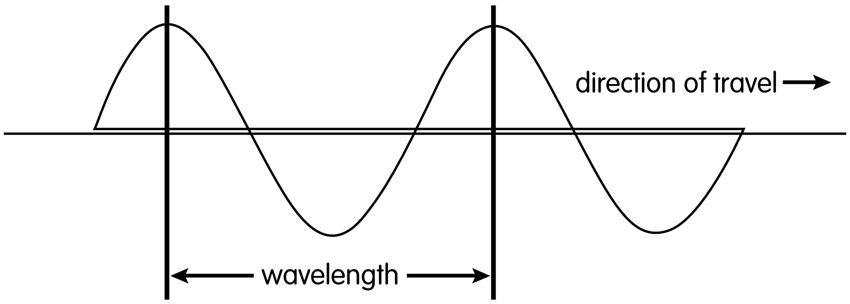


Fig. 2. The wavelength of electromagnetic radiation.

cycles per second) on the FM (frequency modulation) dial. Notice on the legend under Fig. 1 that energy and frequency increase together toward the left side of the figure, whereas the wavelength increases toward the right side of the page. That is because the wavelength and frequency are related to each other:

$$\text{wavelength} \times \text{frequency} = \text{the speed of light}$$

or

$$\lambda \times f = c$$

In this equation, the Greek letter "lambda" (λ) is used as shorthand for the wavelength and the fancy "f" (f) is used to represent the frequency; "c" is the speed of light (186,000 miles per second or 300 million meters per second). Since the speed of light is constant, the wavelength and frequency are limited; if one is big the other has to be small. That is why large (high) frequencies correspond to small wavelengths and large wavelengths correspond to small (low) frequencies. This same relationship (also known as "the wave equation") applies to all waves, including electromagnetic waves, waves on a rope (here the speed of light is replaced by the speed of the wave in the rope), or any other kind of wave. It's a universal relationship.

In some cases, especially when light interacts with atoms, it behaves more like particles than like waves. These particles are called photons. Each photon of light represents a distinct bit of energy; the greater the frequency of the light, the greater the energy. Using the same notation as above,

$$\text{Energy} = h \times f = h \times (c \div \lambda)$$

where "h" is a number called Planck's Constant. (Planck was a German physicist who studied the electromagnetic spectrum, and how light interacts with matter.) Consider how factors are related in this equation; if the frequency is doubled, so is the energy. If the frequency is decreased by half (50%), energy is decreased by half. The second relationship comes from the wave equation, already discussed; it has simply been rearranged by dividing each side by the wavelength, so that

$$f = c \div \lambda$$

Look what happens to energy if the wavelength is doubled: the energy is halved. If the wavelength is halved, then the energy is doubled. In this way, energy is inversely proportional to wavelength. The bigger (longer) the wavelength, the less the energy associated with that part of the electromagnetic spectrum. The shorter the wavelength, the greater the energy. Referring again to Fig. 1, one can see that when we say a light is of a certain color, we are really saying that the energy it radiates is of a certain frequency, or wavelength, which our eyes interpret as useful information.

3. Where does electromagnetic radiation come from?

Electromagnetic radiation is one of nature's ways of moving energy from one place to another. In physics language, this is called energy transfer. For instance, think about a neon lamp, such as a store sign. High-voltage electricity flows through the neon gas in the lamp, and some of the electrical energy gets captured by neon atoms. The captured energy is stored in the atoms' electrons, by moving them away from the atoms' nuclei. The electrons can then move back to their usual places in the neon atoms by releasing some energy as a photon of

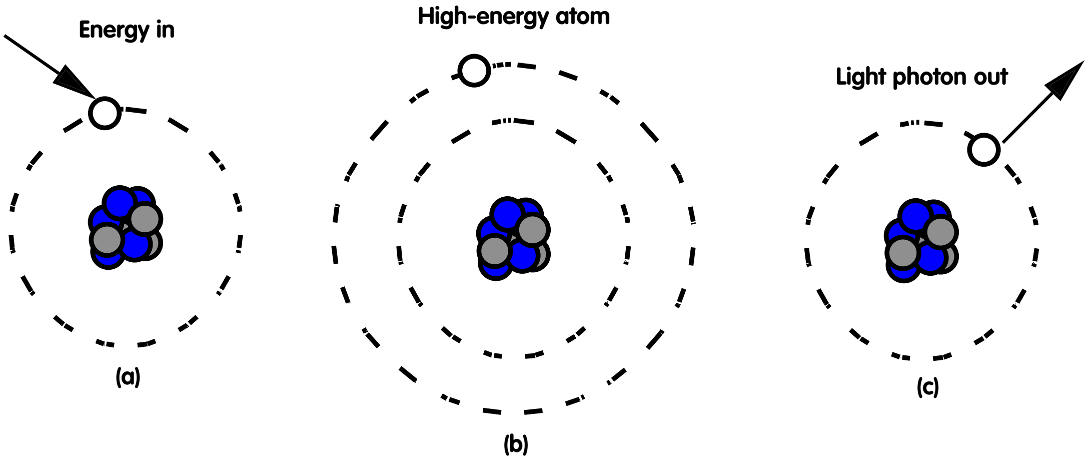


Fig. 3. Emission of light (a photon) by an atom. Moving from left to right, **(a)** energy is given to an electron in a neon atom (small circle) — the nucleus is composed of protons (black) and neutrons (gray); **(b)** the electron jumps to the higher energy shell due to its newfound energy; however, this situation is unstable and the electron falls back to its original energy shell; and **(c)** in so doing, it gives off the energy given it originally by emitting a photon. The photon's energy is equal to the difference in energy between the original electron shell and the shell to which the electron had been temporarily "promoted."

light. This light is the orange-red glow of the neon lamp. This process is shown in Fig. 3. Because the electrons in neon atoms (and all other kinds of atoms) are arranged in a very precise and orderly fashion, neon atoms can only give off certain energies (or frequencies or colors) of light as the electrons move back to their original locations. The energy difference between where the electron starts and finishes is the energy that will be given to the photon of light.

Most atoms absorb energy and reemit photons almost instantaneously; the amount of time required to move between electron shells in an atom has never been measured, except in the sense of ". . . the time was less than X to go from one shell to the other." Some atoms, however, save the energy for long times, and so give off photons long after the energy source has gone. This delayed emission of light is *phosphorescence*; you've all seen phosphorescence as "glow in the dark" stickers, T-shirts, Frisbees, etc.

Materials can also emit light of different energies (or wavelengths) than they absorb. This effect is *fluorescence*. Most often, the emitted light has a lower energy (longer wavelength) than the absorbed light. So, most often any fluorescence we can see is produced by light with higher energies (shorter wavelengths) than visible light. This shorter-wavelength light is ultraviolet, the kind that causes sunburn. Fluorescent lamps produce ultraviolet light first to make their light. Inside a fluorescent lamp tube, there is a mix of gases with a little bit of mercury. When high-voltage electricity passes through the gas, its atoms absorb some of the electrical energy and their electrons get elevated, just like in a neon lamp (see Fig. 3). The gas in a fluorescent lamp radiates ultraviolet light as its electrons return to their home positions. The ultraviolet light is then absorbed by a thin coating on the inside of the lamp tube (this coating looks white when the lamp is off); electrons in this coating are pushed to high-energy positions. The coating then fluoresces — emits visible light — as its electrons return to their homes.

Reflectance Spectroscopy

The ALTA Reflectance Spectrometer measures how much light, of different colors or wavelengths, reflects off objects. This kind of measurement is *reflectance spectroscopy,* and is a basic technique in most environmental studies of the Earth and studies of the planets. In reflection spectroscopy, the light does not originate on the object you are sensing; it comes from somewhere else. For instance, Mars is visible in the sky because light from the Sun reflects off it to Earth and our eyes. Measurement of the light that objects emit themselves is called *emission spectroscopy,* which the ALTA cannot do. Stars can be studied by emission spectroscopy, because they give off light of their own. Emission spectroscopy of heat radiation is sometimes used in environmental studies. Measurement of light that passes through objects is called *absorption spectroscopy,* which the ALTA cannot do well. Absorption spectroscopy is used to study relatively transparent things, like the Earth's atmosphere. Our knowledge of ozone abundances and holes in the Earth's upper atmosphere comes from absorption spectroscopy.

1. What happens when light hits an object?

When light hits an object, some of it reflects off and into our eyes or the ALTA spectrometer. But not all the light will reflect off — some of it may be absorbed by the object, and some of it may be transmitted through it (Fig. 4). These three processes should account for all the light:

All light = reflected light + absorbed light + transmitted light.

This equation is part of the Conservation of Energy principle of physics, which says that energy cannot be created or destroyed (remember that light is a form of energy). The ALTA Reflectance Spectrometer can only measure how much light is reflected from an object.

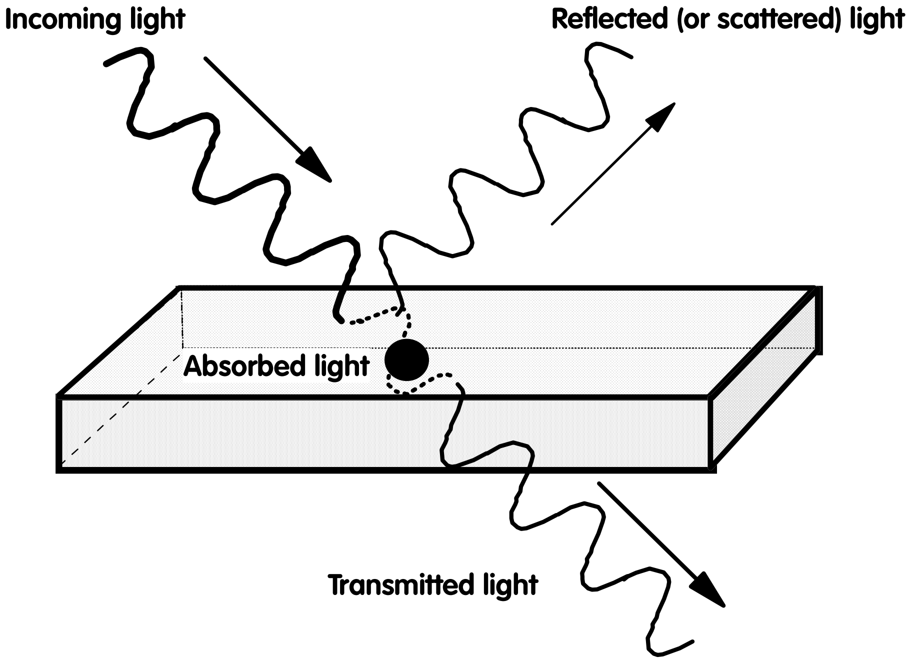


Fig. 4. Light that hits an object is either absorbed, transmitted, or reflected.

2. Reflectance spectroscopy

What actually happens to light when it interacts with objects is complicated — the stuff of advanced physics classes. It is enough to know that objects can absorb or reflect different wavelengths of light to different degrees, and that different objects absorb or reflect light differently. Most of the solid objects you'll look at with reflection spectroscopy don't transmit very much light through them, so the equation above becomes even simpler:

All light = reflected light + absorbed light

All the light that isn't absorbed by the object must reflect (or scatter) off it. So, the way light is *absorbed* by an object usually dictates what its reflected light looks like. For instance, if an object absorbs no light, whatever hits the object reflects (or scatters) off. Our eyes see objects like this as white (Fig. 5). On the other hand, if all the light that hits an object is absorbed, there is no light left over to reflect off and come to our eyes or the ALTA spectrometer (Fig. 6). An object like this appears black.

But what if only some colors are absorbed? Say a piece of fruit absorbs all the purple, blue, green, yellow, and orange light that hits it, and doesn't absorb all the red light that hits it. What color will this fruit appear to your eye (or to the ALTA spectrometer)? Since only part of the red light is absorbed, the rest must be reflected from the fruit. So the eye responds to the only light it receives, the red light, and you will see the fruit as red (Fig. 7). With your knowledge of color (reflection spectra) of many fruits, you can decide that this fruit is not an orange, a grapefruit, a pear, a peach, a banana, or a grape. You might need more clues (like its shape) to tell if the fruit is an apple or a tomato.

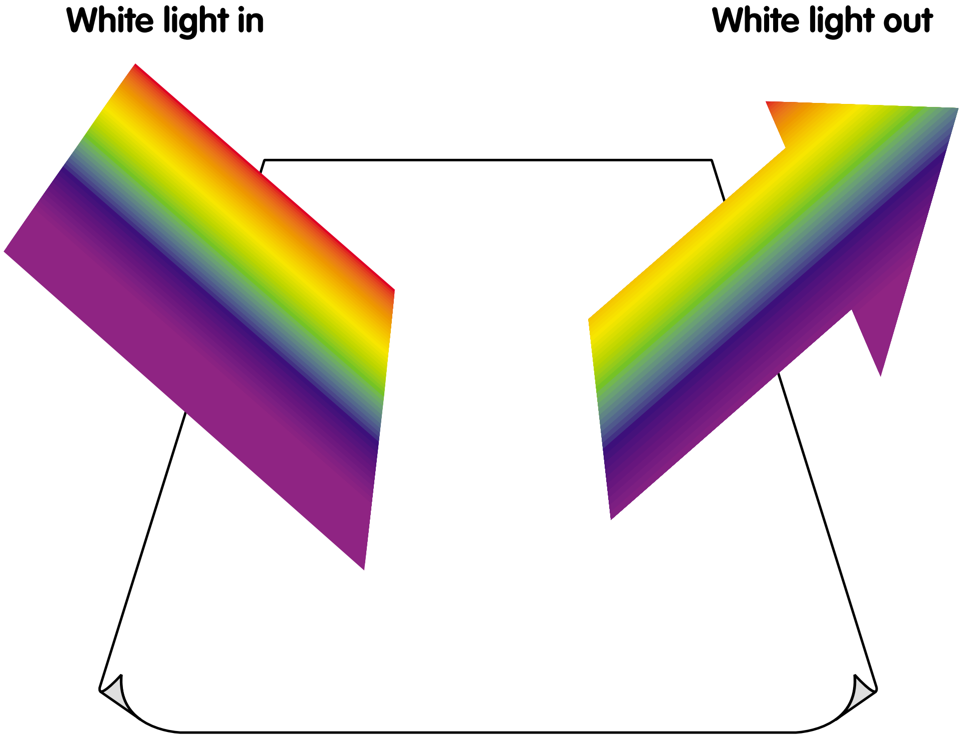


Fig. 5. If no light is absorbed by an object, it appears as white.

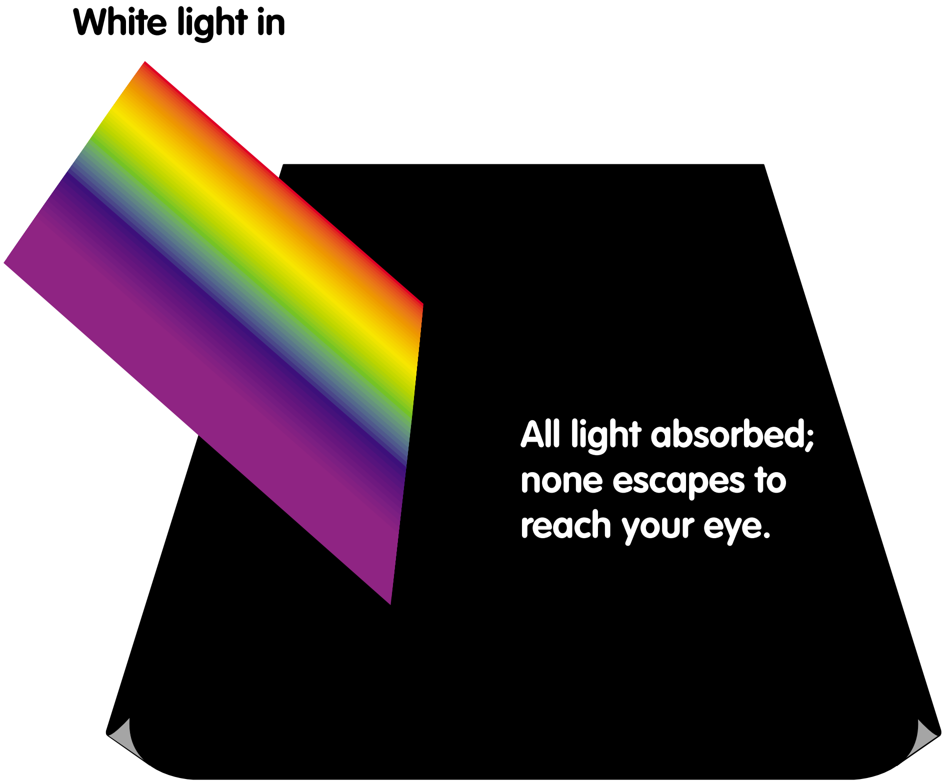


Fig. 6. When all visible light is absorbed by an object, it appears black.

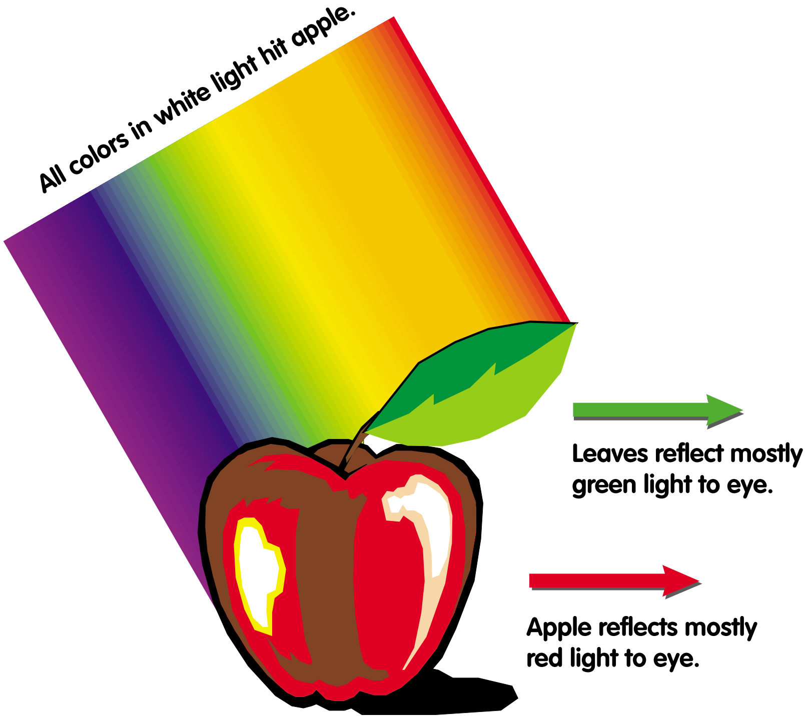


Fig. 7. An apple appears red, and its leaf green, depending on which colors are reflected back to the eye.

For another example, look at the green leaf on the apple. Because you see it as being green, you know that the leaf must be reflecting green light to your eyes. Also, the leaf is *not* reflecting much light in blue, yellow, orange, or red. So what wavelengths of light is the leaf absorbing? The leaf absorbs wavelengths that correspond to blue, yellow, orange, and red. In a green leaf, the chemical chlorophyll is the culprit that absorbs the light and then converts its energy into food for the plant. Surprisingly, the green color of leaves is not really from the chlorophyll — it is from the light that the chlorophyll doesn't absorb.

These differences in absorption and reflectance of different colors of light give us important clues to understanding and interpreting the world around us. Reflection spectroscopy does the same — although it does it better in some ways than our eyes can. With reflection spectrometer instruments (like the ALTA), we can sense many distinct wavelengths of light, while our eyes are sensitive to only three. With a reflection spectrometer, we can also measure and quantify how much light is reflected from an object. The numbers we can measure (the reflectances) hold clues to the nature of the objects we measure, whether they are in the laboratory (as with the ALTA), on the Earth's surface below a satellite, or on the surface of Mars.

LESSON BASICS

1 Explore the Spectrometer

Objectives

☞ Learn the parts of a spectrometer.

☞ Learn what the spectrometer responds to and how it might be used.

☞ Learn about the quantitative measurement of a physical property.

About this lesson

This lesson introduces the students to the ALTA Reflectance Spectrometer. It is meant to be an exploration of the buttons, lamps, and readout of the spectrometer. The students will learn most of what the spectrometer does through hands-on investigation. They should discover that (1) the colored buttons on top of the spectrometer turn on corresponding lamps on the bottom; (2) the switches colored black and gray do not appear to turn on any lamps; (3) the numbers in the spectrometer's display window change with different lighting; and (4) the display goes mostly blank in very bright lighting.

The students will take simple measurements with the ALTA spectrometer and show that their ordering of materials by the lightness of their color corresponds closely (exactly, we hope) to the reflectance numbers from the ALTA.

Note: Remind students to keep fingers, pencils, and other objects away from the spectrometer's lamps.

Materials

✔ ALTA spectrometers (one per group of two or four students).

✔ Colored materials, with flat surfaces of every sort imaginable, from bright to dull, light to dark, in all colors of the rainbow.

✔ Data sheet and graph template (included).

Background

This exercise will acquaint the students with the ALTA spectrometer and allow them to learn the ALTA's operation through hands-on exploration. Experience has shown that students enjoy working with the ALTA; it is easy to hold and looks like a science-fiction device with switches, blinking lights, and changing numbers. While relatively simple, the ALTA spectrometer is similar enough to planetary and satellite instruments to give students a good feel for how the more complicated instruments work.

Vocabulary

Spectrometer, infrared, calibrate

Essential knowledge

1. Use tools to collect, analyze, and record information.
2. Organize, analyze, evaluate, and make inferences from direct and indirect evidence.
3. Construct graphs, tables, maps, and charts using tools, including computers, to organize, examine, and evaluate data.

Procedure

PREPARATION

1. Ensure that spectrometers are all working and that batteries are charged.
2. Assemble the variety of different-colored objects into color groups: all green together, all red together, etc.

CLASSROOM PROCEDURE 1: EXPLORATION

Hand out the ALTA spectrometers (one per student or group). Show the students how to turn the spectrometer on (by pressing the switch on the keypad), and ask them to explore what the ALTA does. Warn them not to stick their fingers or other objects inside the ALTA. Students should quickly discover that the colored switch pads turn on lamps on the underside of the ALTA, that the black and gray buttons do nothing obvious, and that the display numbers on the ALTA face change. Encourage the students to explore what makes the numbers change — for example, ask them to point the bottom hole of the spectrometer at a lamp and then cover the hole up with their hand. Ask the students to put the spectrometer flat down on their desk (or table) and to note how the display number changes as they push the different buttons.

After an appropriate time, review with the class what they discovered. They should all know that the colored buttons turn on lamps of the corresponding color, that the display number is higher when more light gets in the bottom of the ALTA, and that the display shows only a “1” with bright light (i.e., overload). They also may have discovered that pushing the black and gray buttons may make the display number increase, even though they cannot see any lamps light up with their eyes. (Some students may be able to see red light from the IR1 lamp.) Ask the students where the ALTA’s sensor might be.

CLASSROOM PROCEDURE 2: “BRIGHTNESS” AND THE SPECTROMETER

1. Remind the class what the spectrometer does. Remind them that the switch pads turn on little LED lamps, and that the number on the front measures how much light hits the spectrometer’s light sensor, which is in the center of the LED lamps on the underside of the ALTA.
2. Discuss the concepts of visible color and wavelengths of light reflected from a surface (see Introduction).
3. Assign each group of students a color (e.g., red, blue, yellow). Give each group a set of objects of that color, including very bright (or light) and very dark shades.
4. Ask each group to arrange their objects in order of increasing brightness or lightness. List the objects in order of brightness on the attached data sheet.

5. For each colored object, measure its brightness using the ALTA spectrometer.
    (a) Place the ALTA spectrometer on the object, with the keypad and display facing up and the hole pointed toward the object.
    (b) Press and hold down the switch pad on the ALTA that turns on the lamp of the group's color (e.g., red, blue, yellow).
    (c) On the data sheet with the list of objects in order of brightness, write down the display number (with the switch held down) for the object on the same line as the name of the object.
6. Make a bar graph of your results. Each group should graph its results on the attached graph template (or something similar).
    (a) First, write in the names of each object, in order of increasing brightness or lightness, in the spaces along the bottom of the graph.
    (b) Then, for each object, make a bar that extends up as far its display number reading that you wrote on the data sheet.
7. Discussion: Do lighter-colored objects show higher numbers (greater reflectance) as measured by the ALTA? (In theory, the "lightness" of the object should track the numbers exactly.) Does the ALTA measure the same kind of "lightness" as your eyes?

Extensions

1. *Quantification.* Much of our culture is based on quantification of the world around us — giving numbers to the things and events we experience. The two ways numbers used here are *ranking* and *quantification*. Ranking is ordering things according to some property as first, second, third, etc. For instance, winners in a foot race are ranked first, second, third, etc. Quantification is measuring a property or event with a natural number. For instance, one might run the 100-yard dash in 9.88 seconds. Ranking can be based on a quantified number — 9.88 seconds might be the fastest and so qualify for first prize. Give some examples of things in our world that are ranked by a quantified property (e.g., foot races), things that are ranked without a quantified property (e.g., beauty contests), and things that are quantified without needing a ranking (e.g., radio station frequency, blood pressure).
2. Discuss what kinds of jobs are available in research science, including such fields as planetary geology, exobiology, and astronomy. Discuss how astronomers use both visible and invisible light to investigate the heavens.

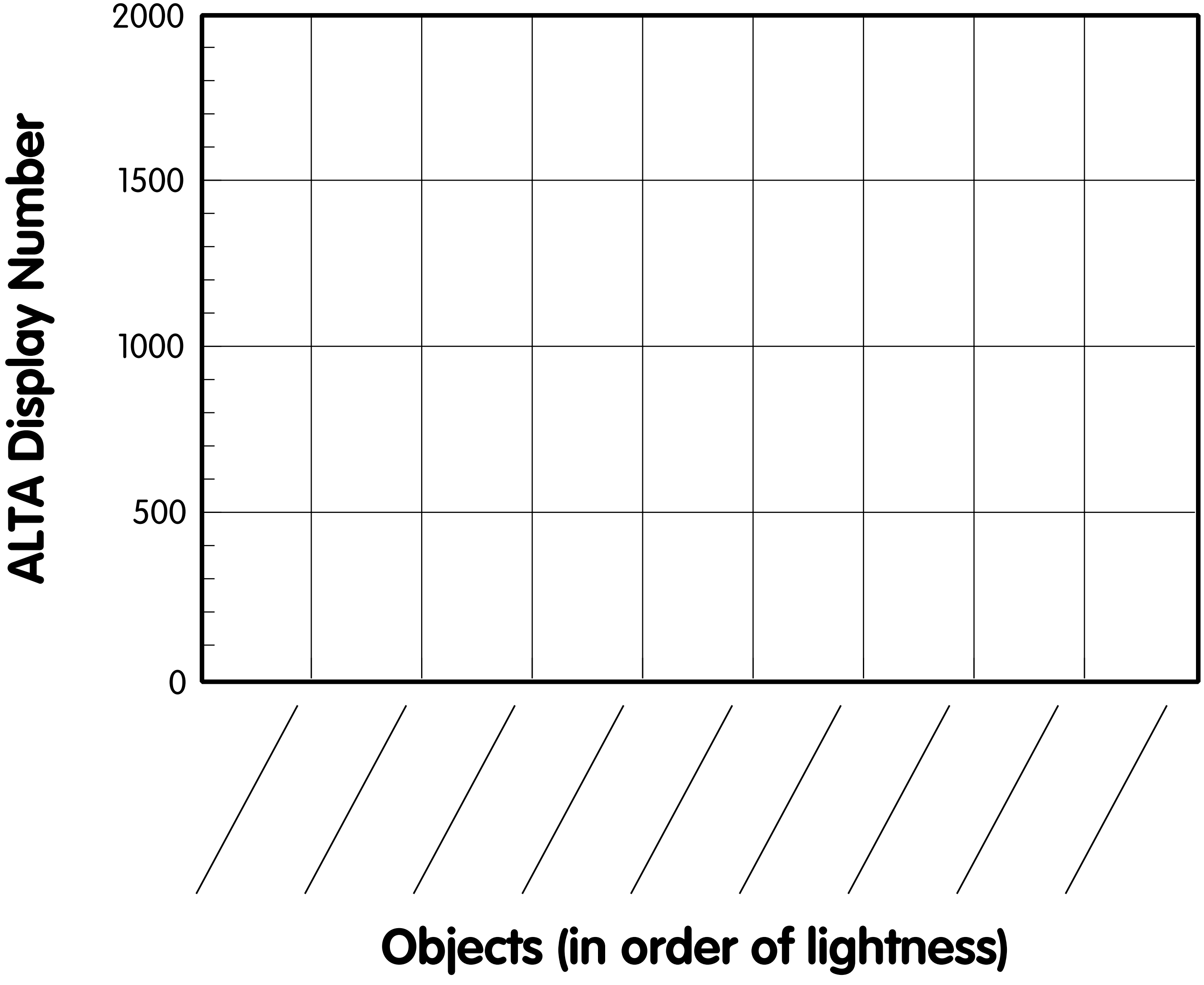
Lesson 1: Data Sheet 1.

Scientist(s): ____

____

Color =		
	Object	**ALTA Display Number**
Darkest object		
Brightest object		

Lesson 1: Graph Template 1.



2 Visible and Invisible Light

Objectives

- ☞ Explore the human eye's responses to the spectrum from white light (the rainbow).
- ☞ Explore the ALTA sensor's responses to the spectrum from white light.
- ☞ Demonstrate the existence of light the ALTA can sense that the students' eyes cannot.
- ☞ Learn that the ALTA's sensor is blind to purple (violet) light.

About this lesson

The students will observe that there is "light" that is not visible to the human eye. They will produce a rainbow, or spectrum, from white light and explore the responses of their eyes and the ALTA spectrometer to the spectrum. In general, this exercise will show that all sensor systems (eyes or electronic) have limitations. This lesson assumes that the students have used the ALTA spectrometer; if not, they should start with Lesson 1.

Materials

- ✔ ALTA spectrometers.
- ✔ A means of producing a rainbow spectrum, projected onto a wall or a piece of paper. This requires three parts:
    - ❖ An incandescent light source (not fluorescent), like a slide projector or overhead projector;
    - ❖ a 1/4" slit or small hole in a piece of opaque material (thick black paper or poster board), at least 5" × 8" (to keep stray light out) to help make a beam of light; and
    - ❖ a prism or diffraction grating to disperse the light into its colors — other ways to disperse light into its rainbow colors include "light-catcher" window ornaments, or square or triangular-shaped bottles (like olive oil and some spice bottles) full of water.
- ✔ Tape, modeling clay, small boxes, hanger wire, etc., to hold the prism (or whatever) in place.
- ✔ A yardstick, tape measure, or meter stick.
- ✔ "Glow in the dark" or Dayglo material such as a crayon or marker (optional).
- ✔ Data sheets (included).

Background

These days, many students are acquainted in practice with invisible light, although they may not make a full connection between it and the visible spectrum. Ultraviolet light, with wavelengths shorter than violet light (see Introduction), is invisible. Students are probably familiar with ultraviolet light as the cause of sunburn, and the "black light" that makes some posters glow. Ultraviolet light from the Sun has been in the news as a cause of skin cancer and is more abundant now than in the past because of ozone depletion in the upper atmosphere. Infrared light, with wavelengths longer than red light, is invisible. Students are probably familiar with infrared light; remote controls for TVs and VCRs use infrared light, as do many security systems that detect motion.

Vocabulary

Spectrum, light, infrared, ultraviolet, vision

Essential knowledge

1. Use tools to collect, analyze, and record information.
2. Organize, analyze, evaluate, and make inferences from direct and indirect evidence.
3. Construct graphs, tables, maps, and charts using tools including computers to organize, examine, and evaluate data.
4. Identify uses of electromagnetic waves in various technological applications such as fiber optics, optical scanners, and microwaves.

Procedure

PREPARATION 1: MAKING RAINBOWS (VISIBLE LIGHT SPECTRA)

1. Arrange the lamp and the slit to produce a thin beam of light. On a slide projector, the slit can be taped over the lens. On an overhead projector, the slit can sit on the flat surface, illuminated from below (see Fig. 1).
2. Rotate the prism or diffraction grating over the slit or pinhole until a rainbow spectrum is visible on the wall, whiteboard, or table. This will take some experimentation, but it will work. Figure 1 shows four arrangements that have worked. You should experiment with other arrangements if these are not feasible.
3. Use the modeling clay (plus boxes or whatever) to mount the prism in the orientation that produces a rainbow. This allows your hands to be free for other activities.
4. Using the ruler, mark a distance scale next to the rainbow or ensure that a ruler or meter stick can be used to mark positions in the rainbow. The scale must extend beyond the purple and also beyond the red.
5. Record the location of the slit and orientation of the prism in your notebook so you can do this again.

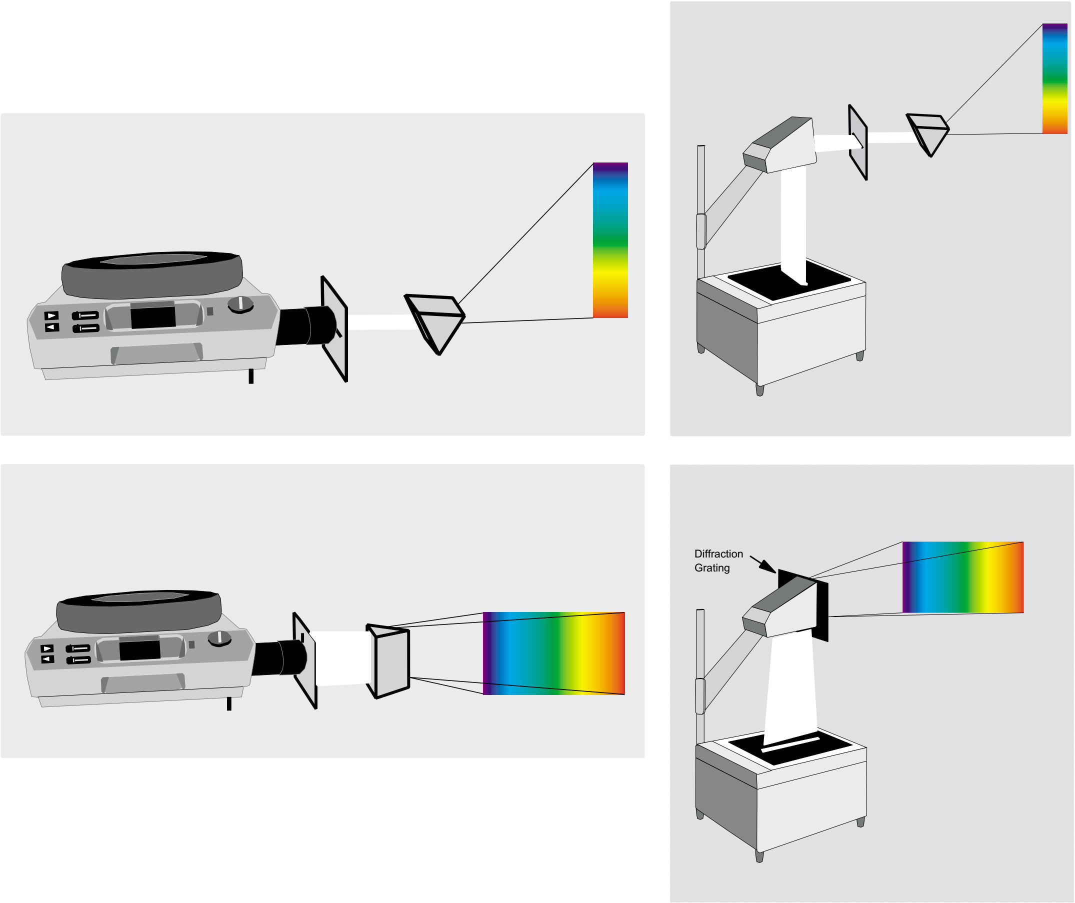


Fig. 1.

PREPARATION 2: DAY OF LESSON

1. Set up the lamp/projector to make a rainbow spectrum for the class.
2. Place ruler, distance marker, or meter stick where spectrum is projected.

CLASSROOM PROCEDURE

1. Darken the room (the darker, the better) and project the rainbow onto the whiteboard, paper, or wall.
2. Have each student look at the rainbow and, using the ruler, record (on the attached data sheet #1) the ruler or meter stick distance at the first visible red light, the boundary between red and orange, the boundary between orange and yellow, and so on, to the limit of visible purple light.* Also on data sheet #1, have them note the ruler distance that seems the brightest to them.
3. Talk with your class about where the boundaries of the colors are. Students may see the boundaries in different places — colorblind students will have difficulty with some boundaries.* Other students may differ in locating the color boundaries, particularly between green and blue. **This is normal.**
4. Talk with your students about the limits of human vision. Students may see the limits of vision in different places (depending on their overall visual acuity and on physiological factors).

5. Talk with your students about what kind of light is beyond purple or beyond red (see "Introduction to Electromagnetic Radiation and the Spectrum").
6. Turn on the ALTA spectrometer and have a volunteer or several volunteers measure how it responds to light in the rainbow. (The colored lamps are not used in this exercise.)
   (a) First, take a background light reading near the rainbow but not in it, with the ALTA spectrometer's bottom hole pointing generally toward the source of the rainbow spectrum (i.e., the projector). This gives a reading for the level of room light so you know how the spectrometer is responding to the general room light without the spectrum. Write this number on the attached data sheet.

   (b) Take about 10 measurements at distance positions throughout the rainbow, including at least one beyond the purple and a couple beyond the red. Again, orient the spectrometer so that the rainbow light enters the hole on the spectrometer bottom. Write these distances, their spectrum colors, and their ALTA display numbers on the data sheet. If the display shows "1," there is too much light getting into the ALTA, and you may want to take all your measurements near the edge of the rainbow spectrum rather than the center.

   (c) From each measurement, subtract the background light measurement (in the data table attached); the result is how the ALTA spectrometer responded to the rainbow color itself.
7. Talk with the students about the results from the ALTA spectrometer and how they compare with human vision. The ALTA should get very little response to the spectrum at purple or beyond and fairly weak response to blue. The ALTA should also get a very strong response to red light, and an even stronger response to the spectrum area beyond red. How does this compare to human vision? What is happening beyond red in the rainbow? The ALTA behaves as if light were hitting it, but people see no light there. Can it tell whether red light or blue light is hitting it? The main lessons to be learned here are that light sensors can detect different kinds of light, and that something happens beyond red light that we can't see, but that other sensors can. This "something" is infrared light, which behaves just like visible light in all ways except that humans can't see it.
8. *Optional demonstration.* Take the glow-in-the-dark material and observe it as you move along the rainbow. With luck, you will be able to see that it glows some at the blue-purple end of the rainbow and beyond to where there is no visible light. This region is ultraviolet light, which behaves just like visible light except that it is not visible to our eyes. This exercise will not always work. Normal incandescent lights do not make much ultraviolet light (of lights likely to be found in a classroom, slide projectors generate the most ultraviolet light). So, you will need a very dark room.

Extensions

1. *Invisible light in your life.* How is your life affected by invisible light? What does ultraviolet light do to people? [Causes sunburn.] How do people use ultraviolet light? [Blacklight posters, tanning, crime labs, and investigations.] How do people use infrared light? [Remote controls for TVs and motion detectors for security systems.]
2. *Invisible light — library research.* Who discovered infrared light? Ultraviolet light? How were these invisible kinds of light discovered? Which animals can detect ultraviolet or infrared light? How would it be possible to discover that animals detect light that is invisible to humans?

3. *Animal vision.* Can all animals see in color? Why might it help an animal in its daily life to be able to see in color? What are some animal “lifestyles” where color vision would not be helpful? For more information, consult the following sources.

   📖 “Color Vision in Fishes” by J. S. Levine and E. F. MacNichol, Jr., in *Scientific American,* Feb. 1982.

   📖 “Mating Strategies in Butterflies” by R. L. Rutkowski, in *Scientific American,* July 1998.

4. *Radio astronomy.* Discuss radio astronomy, including its techniques and history.

5. *Art.* Discuss how light and shadow are used to show dimensionality in art. Trace the history of perspective in art and show examples of primitive cave drawings compared to works by Michelangelo, Leonardo da Vinci, M. C. Escher, and Georgia O’Keefe.

6. *Quantifying infrared wavelengths (advanced).* Using the spectrum you projected on the wall and a ruler, it is possible to calculate light wavelengths in the infrared portion of the spectrum and thereby make quantitative measurements of the ALTA spectrometer’s responses to different wavelengths. This exercise relies on the fact that prisms and diffraction gratings spread light out (disperse it) linearly with respect to light wavelength:

   wavelength = (constant #1) + (constant #2) × (measured distance along the ruler).

   Here, students will determine the values of the two constants, and so teachers will need to have a calibration for light wavelengths in regions where they cannot use visual color as a guide to wavelength.

   (a) On the rainbow on the wall, measure the positions (ruler distances) of the centers of the green, yellow, and orange colors. These positions should correspond to light wavelengths of ~555, 585, and 635 nm (nanometers) respectively. Make a graph of your data, with ruler position on the vertical and light wavelength on the horizontal. The ruler position axis should span the positions of the whole visible rainbow, plus a little extra beyond the position of red (see the table you made above in part 2); the wavelength axis should extend from 300 to 1200 nm.

   (b) Plot your data on this graph — the three data points (green, yellow, and orange) should mark out a straight line (or nearly so). Draw a line through the three data points and extend it to the limits of the wavelength axis (300–1200 nm). This graph is now a calibration for your rainbow spectrum — from a position you measure on the rainbow, the graph allows you to get the wavelength of the light there. Does your calibration fit with published spectra as to the limits of visible red and purple? What about to the boundaries between red and orange, green and blue, etc.?

   (c) *ALTA sensitivity to infrared light.* Repeat step #6 in the classroom procedure above, but starting in the far red and moving toward the position of 1200 nm with many positions, perhaps 10 or so. Keep the ALTA viewing hole pointed toward the rainbow projector when you take the light-intensity measurements. Graph your data as ALTA display number versus light wavelength. Where in the spectrum is the ALTA most sensitive?

   (d) *Library research.* How much light does an incandescent bulb emit in infrared wavelengths? Is it brighter in infrared than in visible?

*Colorblindness

Students who are colorblind will not be able to do this exercise fully. Students with red-green colorblindness will not see boundaries among green, yellow, and red. Students with blue-yellow colorblindness will not see boundaries among blue, green, and yellow. Students with full colorblindness will see differences in brightness, but will see no color.

Students may be unaware that they are colorblind. If a student has particular trouble with color boundaries or places the boundaries in unusual locations, it might be worth pursuing with the student, parents, or school counselor, and possibly arranging for further testing.

As always, extreme care should be used in noting any differences among students, particularly one (like colorblindness) that may be perceived as a disability. On the other hand, a student who is comfortable with his or her colorblindness can be a great help to your class in exploring how color vision works.

Lesson 2: Data Sheet 1.

Scientist(s): ____

____

Color Boundary	Distance on Ruler or Meter-Stick
Limit of visible red	
Red to orange	
Orange to yellow	
Yellow to green	
Green to blue	
Blue to purple	
Limit of visible purple	
Brightest place in rainbow	

Lesson 2: Data Sheet 2.

Scientist(s): ____

____

Position of Measurement Along Ruler	Color	ALTA Spectrometer Display Number	Display Number Minus Background Number
Background — off rainbow	———		———

LESSON BASICS

3 Taking a Reflectance Spectrum

Objectives

☞ Understand spectra by constructing and graphing one.

☞ Collect, manipulate, and graph data.

☞ Understand the purpose of standardization.

About this lesson

This is the most important lesson: how to use the ALTA spectrometer to obtain a reflectance spectrum. Here the students will acquire reflectance data for a green leaf, standardize the results against white poster board and perform the needed data manipulations. Students must understand how the spectrometer works, as covered in Lesson 1. The classroom procedures are given in detail, because of the importance of this lesson and the possibility that the teacher may not be familiar with spectroscopy.

This exercise should give most students a firm understanding of the methods of spectroscopy and what the wiggly line of a graphed spectrum actually means. The ALTA spectrometer gives spectra that are quite similar to those from professional laboratories, and many students feel significant accomplishment at producing results that match those found in a textbook.

This lesson uses a green leaf as the target and can be extended to whatever materials are the focus of your lessons. Some suggested materials are given under Extensions. Lesson 5 involves more focused work on leaves, plants, and remote sensing of vegetation.

Materials

✔ ALTA reflectance spectrometers (one per group).

✔ Green leaves, larger than 1" square (one per group).

✔ White poster board or thick white paper, in pieces approximately 3" × 5" or larger.

✔ Calculator (one per group) optional; math involves long division.

✔ Data tables from template (one per group or student).

✔ Graph from template: voltage vs. color (one per student).

✔ Graph from template: reflectance vs. color or reflectance vs. wavelength (one per student).

Vocabulary

Spectrum, spectroscopy, voltage, volt, millivolt, reflectance, wavelength, nanometer (nm), chlorophyll, carotene, standard, infrared

Background

Green leaves are familiar, and most students know that leaves use sunlight, water, and air to make food for plants. In most plants, the chemical chlorophyll absorbs light energy and converts it to the chemical energy of sugars. Chlorophyll absorbs and uses both blue and red light to make sugars; green light is not absorbed very strongly. Leaves also contain other chemical dyes: carotenes and xanthophylls give red, yellow, and orange colors; and flavonoids give pink to purple colors. The colors of leaves, when seen from a satellite or airplane, allow scientists to tell how ripe crops are, how healthy forests are, where pollutants come from, and so on.

Procedure

PREPARATION

1. Work through the classroom procedure beforehand — take your own reflectance spectrum of a leaf.
2. Photocopy data table and graph templates.
3. Check that all spectrometers are in working order and have batteries.
4. Ensure that calculators are available.

CLASSROOM PROCEDURE

1. *Preliminary.* Outline for your students the procedures for the laboratory. Hand out the spectrometers, data sheets, and one large green leaf per group.
2. *Data collection.* Turn the spectrometers on and remind the students how they work. Place each spectrometer, lamp side down, on a green leaf so the lamp/sensor array is over the leaf. Note the display number (in millivolts) when no ALTA lamps are on; record this on the data sheet as the “dark voltage.” Starting with the blue lamp, turn it on by pushing the blue switch pad on the ALTA face and holding it down. (It may be easier to hold the pad down with a fingernail or a pencil.) The display number will change from its “dark” value and will become constant (except for random variations in the last few digits) within a few seconds to a minute. When the display number remains nearly constant, record it on the reflectance calculation worksheet (either “simple” or “better”) in the “blue” row and the “SAMPLE” column. Using the same procedure, work through the rest of the lamp colors on the ALTA, recording the display number on the data sheet.
3. *Graph raw results.* Graph these raw results on the template “ALTA Display Number vs. Color” or “ALTA Display Number vs. Wavelength.” Does this graph make sense for a green leaf? Sometimes, the number for yellow or blue is larger than the number for green. Sometimes also, the voltage graph shows unexpected bumps, like red being much larger than orange or deep red. There are two reasons for these “anomalies”: (1) the colored lamps are different brightnesses (which you can see) and (2) the ALTA’s light sensor is very sensitive to red and infrared light and barely sensitive to violet light.

   How do the leaf’s display numbers for infrared light compare to other colors?
4. *Standardization.* Take a poll among the students for what their display numbers for green and infrared-3 were. You will find a lot of variation, even though the leaves should be nearly identical. This variation comes from the ALTA spectrometers. Because of variations in the manufacture of the electrical components, lamps, and light sensor, each ALTA has its own unique sensitivity to light (within limits, of course).

To correct for these differences between instruments and to move the measurement closer to what happens to the light, measurement of light reflectance is given as the percentage or proportion of light (for each wavelength or color) that reflects from the leaf. The display number measurements indicate how much light (of each color) has reflected from the leaf, but how much light hit the leaf to start with?

One way to measure how much light hits the leaf, and how much is reflected, is to take reflectance measurements of a *standard* material — something from which we think we know 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, about 85%. White photocopy paper or notebook paper is OK but not ideal — it is thinner than construction paper and allows some light to pass through it (which you can see).

To measure the reflectance standard, put the spectrometer on your piece of white paper and again measure the spectrometer's output voltage for each lamp. Write these numbers in the worksheet in the column labeled "Standard White Paper."

With the "Standard" data, we can now calculate the percentage of light reflected by the leaf. For each color, simply divide the display voltage number for the leaf by the display voltage number for the white paper and mulitply by 100. This value is called the *reflectance.*

% Reflectance = [(Display number for sample) ÷ (Display number for white paper)] × 100.

For your data, calculate the percent reflectance and write them in the table on the worksheet.

If your class is using the "better" worksheet, follow this procedure: The spectrometer display number is usually not zero when there is no light on the sensor. The display value is usually between zero and 150 — this is called the "dark voltage." It comes entirely from the sensor, not from light hitting the sensor. To get a real reflectance value, you should subtract the dark voltage from the measured voltages, and then divide the sample by standard and convert to a percent value.

$$\%\ \text{Reflectance} = \frac{(\text{Display voltage for sample} - \text{dark voltage})}{(\text{Display voltage for standard} - \text{dark voltage})} \times 100$$

5. *Graph.* Graph your standardized reflectance data (as proportions) on suitable graph paper (either the "Reflectance vs. color" or "Reflectance vs. light wavelength" templates). This graph is a *reflectance spectrum.*

6. *Discussions.*

   (a) Is your reflectance spectrum of a leaf reasonable? Compare your leaf spectra to the reference reflectance spectrum of spinach. The spinach reflectance spectrum was taken by the U.S. Army Corps of Engineers in a laboratory using high-tech equipment. While you took measurements at nine different colors of light, the Army Corps took measurements at hundreds of different colors, from violet through infrared. Are your measurements similar to those in the Army's spectrum of spinach? Is your leaf lighter or darker than the spinach (i.e., are your leaf's reflectance values greater or smaller than the spinach's)? Why does the Army's spectrum of spinach show many more wiggles and bumps than yours? [These features include the sharpness of the green reflectance peak, the shoulder on the yellow side of the green reflectance peak, and the steep rise from red into infrared.] Do you think that your leaf spectrum might have similar detail, if you could have measured at hundreds of colors too?

(b) *Biological cause of leaf color.* Why do leaves reflect so much infrared light? Try asking the question another way: Why do leaves reflect so little visible light? What benefit does the leaf or plant get from absorbing visible light, especially blue and red light? What does the plant do with the light it absorbs? What chemical makes leaves green? [chlorophyll] What other colors of pigment are in leaves? [Think about the colors of very young leaves and of dying leaves, especially in the fall.] What benefit might a plant get from having pigments in its leaves? [The red-yellow colors, which mean absorption of blue light, might protect plants (especially young leaves) from sunburn.]

Extensions

1. *Different leaves.* Not all leaves are the same colors: different kinds of plants have different hues of green; young leaves are different colors from mature leaves; and dying leaves are different from mature leaves. Collect a variety of leaves and measure the reflectance spectrum of each. What are the differences among different kinds and ages of leaves. (To compare the spectra quantitatively, you can subtract reflectance values of a pair of spectra or divide them.) Why might leaves have different colors? How might a plant benefit by having dark leaves rather than light-colored leaves?
2. *Different materials.* Take reflectance spectra on different materials. Some materials that can be used include rocks (flat surfaces are best); soils; and different brands of colored ink or paper (like different blacks or different yellows).

Lesson 3: Data Sheet 1.

Class: ______________________________ **Date:** ______________

Scientist(s): ____

____

		Dark Voltage (mV):			
		Voltage (mV)			
Color	Light Wavelength	Leaf 1:	Standard: White Paper	Unknown 2:	Unknown 3:
Blue	470 nm				
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				

Lesson 3: Worksheet for Calculating Reflectance.

(Simple)

Class: ______________________________ Date: ______________

Scientist(s): ____

____

		Voltage (mV)		% Reflectance
Color	Light Wavelength	Sample:	Standard: White Paper	(Sample Voltage ÷ Standard Voltage) × 100
Blue	470 nm			
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			

Lesson 3: Worksheet for Calculating Reflectance.

(Better, but more complicated)

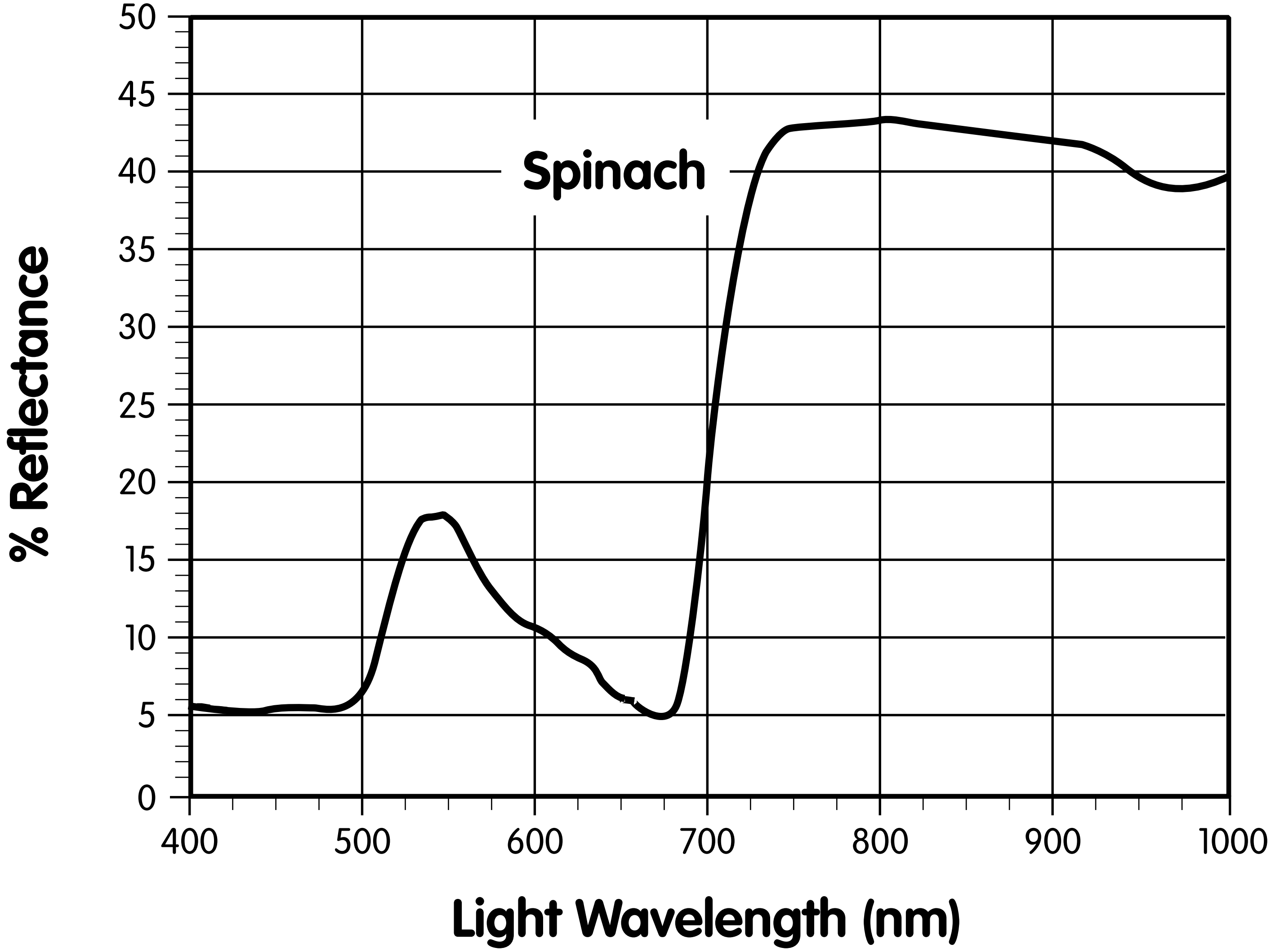
Class: ______________________________ Date: ______________

Scientist(s): ____

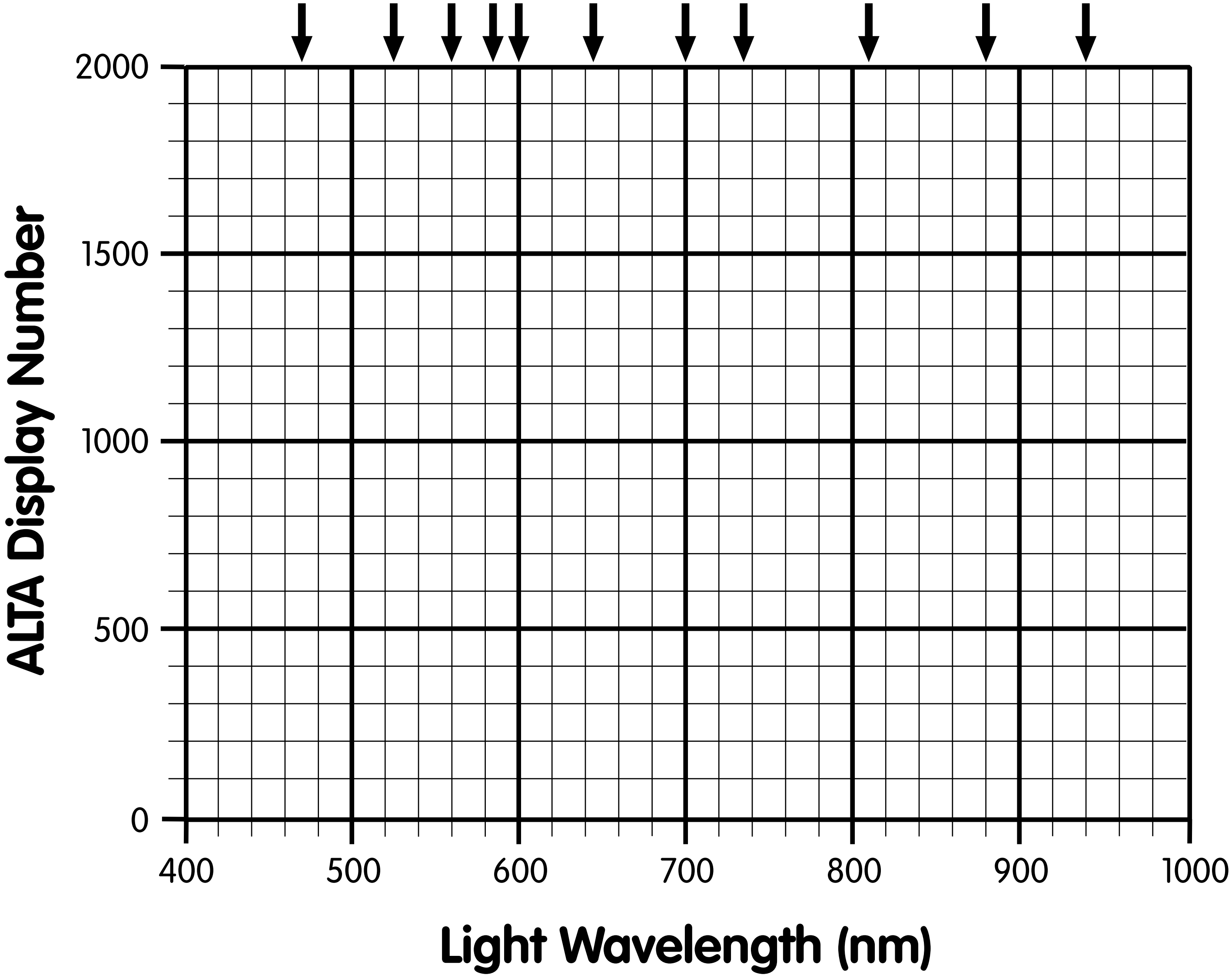
____

		Dark Voltage (mV):		
		Voltage (mV)		% Reflectance
Color	Light Wavelength	Sample:	Standard: White Paper	$\left[\frac{\text{(Sample Voltage – Dark Voltage)}}{\text{(Standard Voltage – Dark Voltage)}}\right] \times 100$
Blue	470 nm			
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			

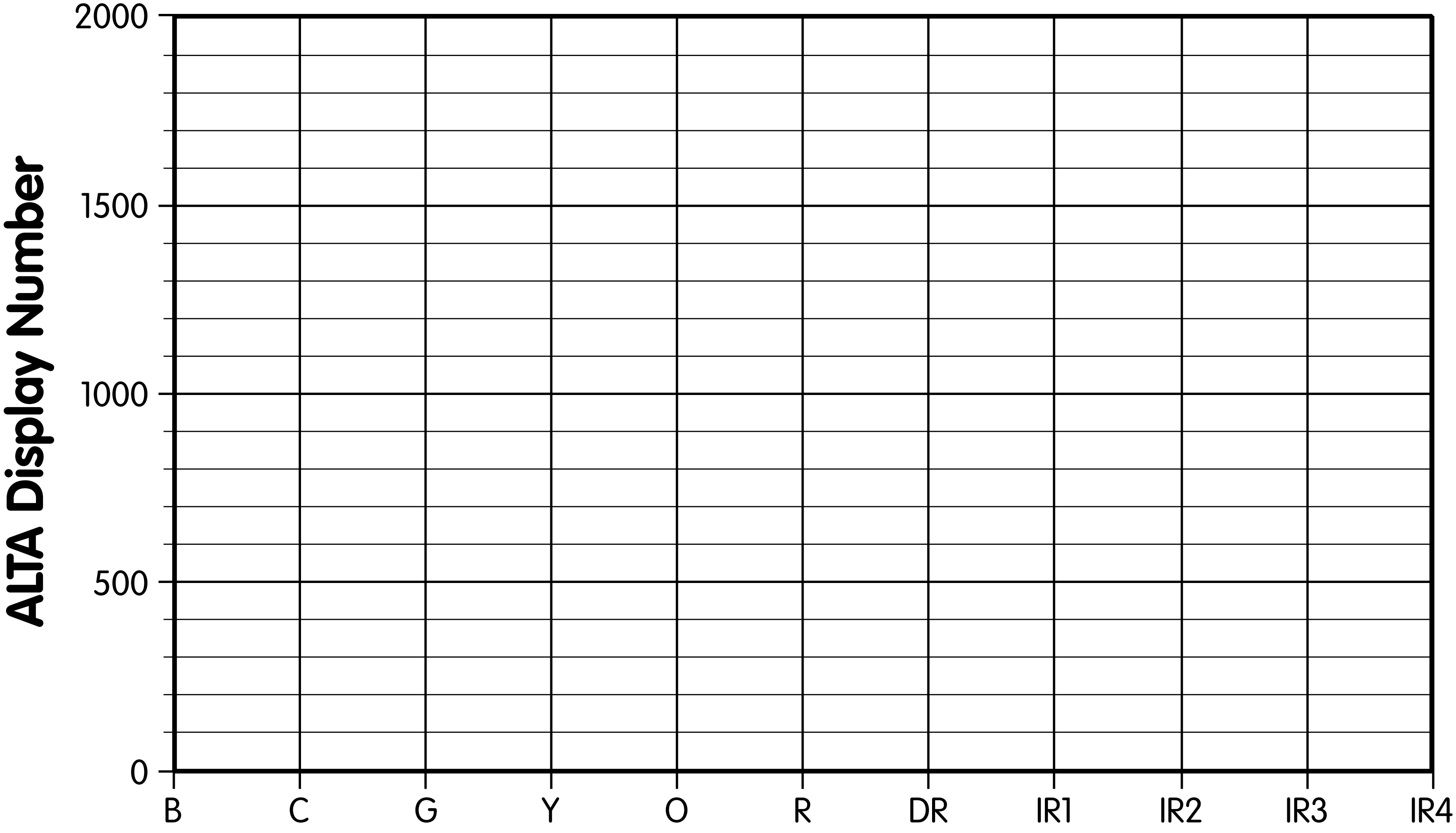
Lesson 3: Reference Spectrum.



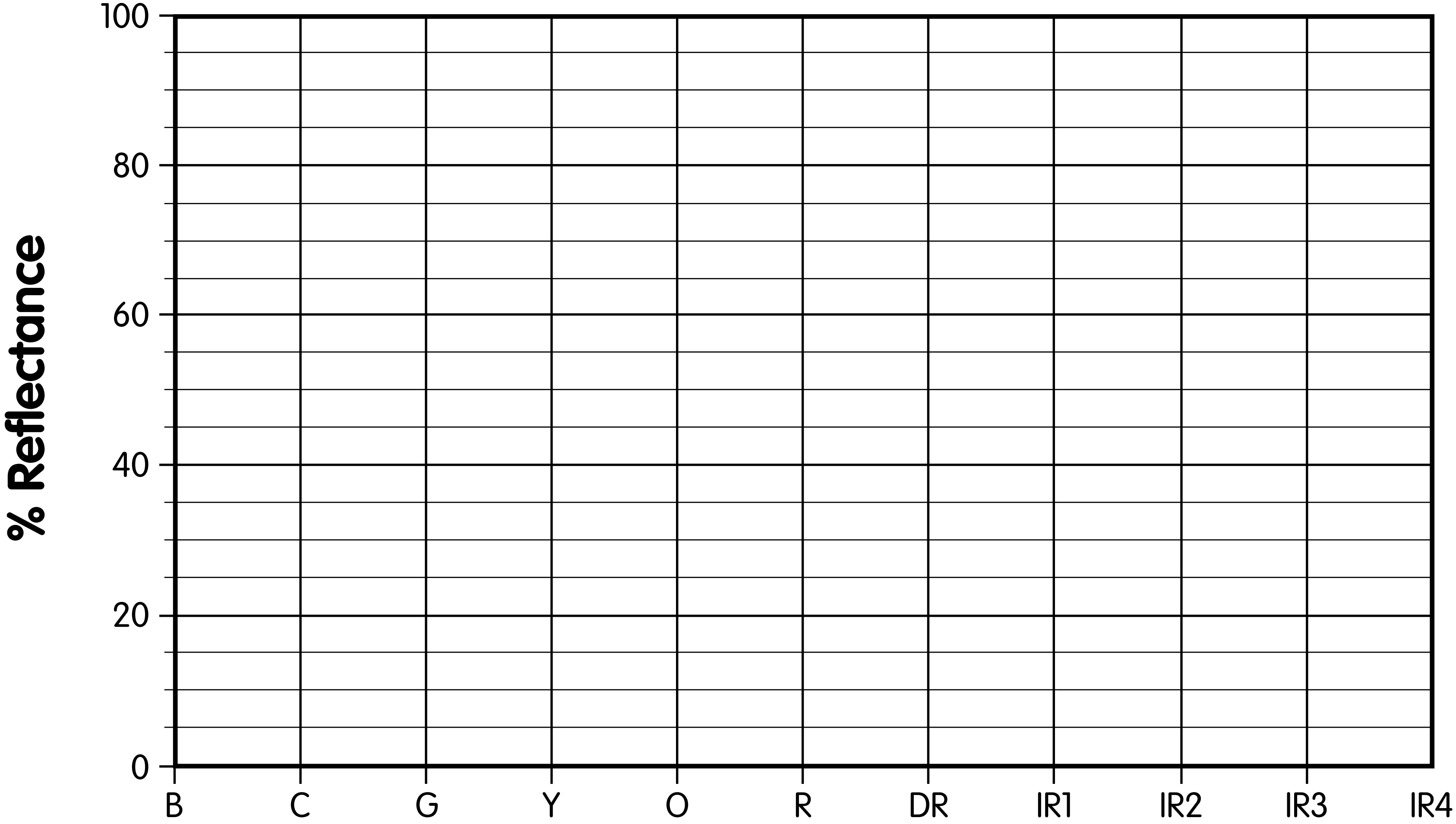
Lesson 3: Graph Template 1.



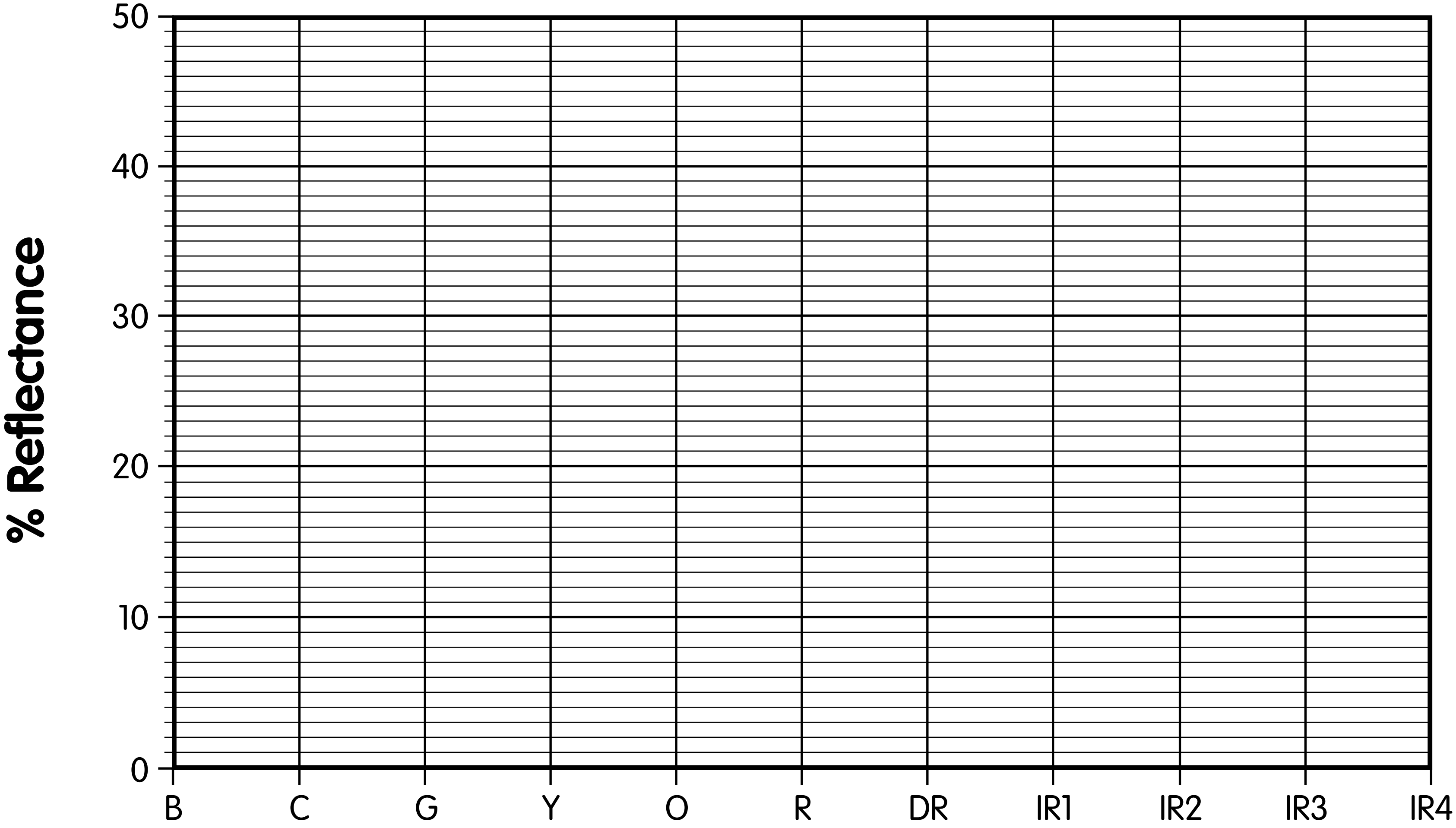
Lesson 3: Graph Template 2.



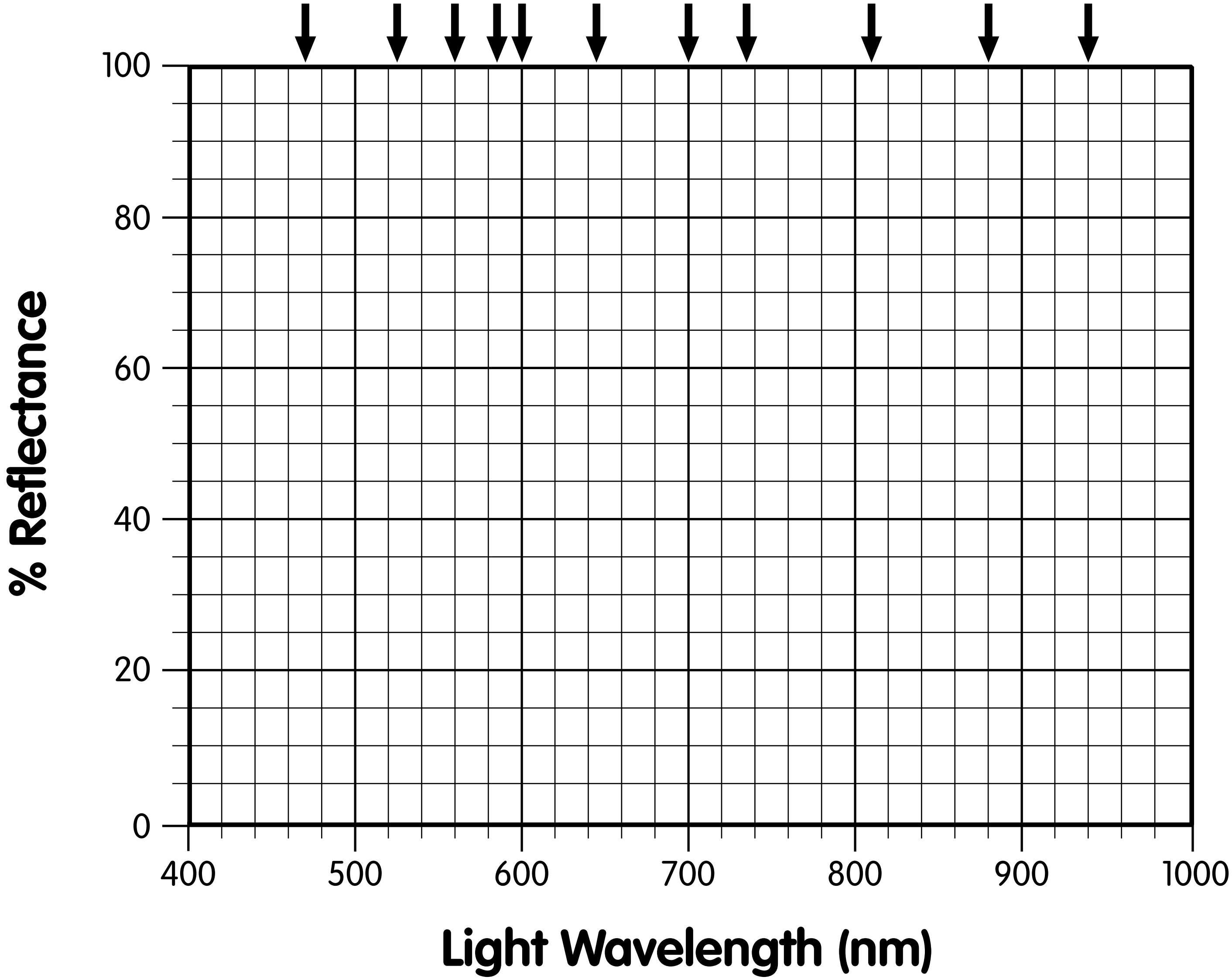
Lesson 3: Graph Template 3.



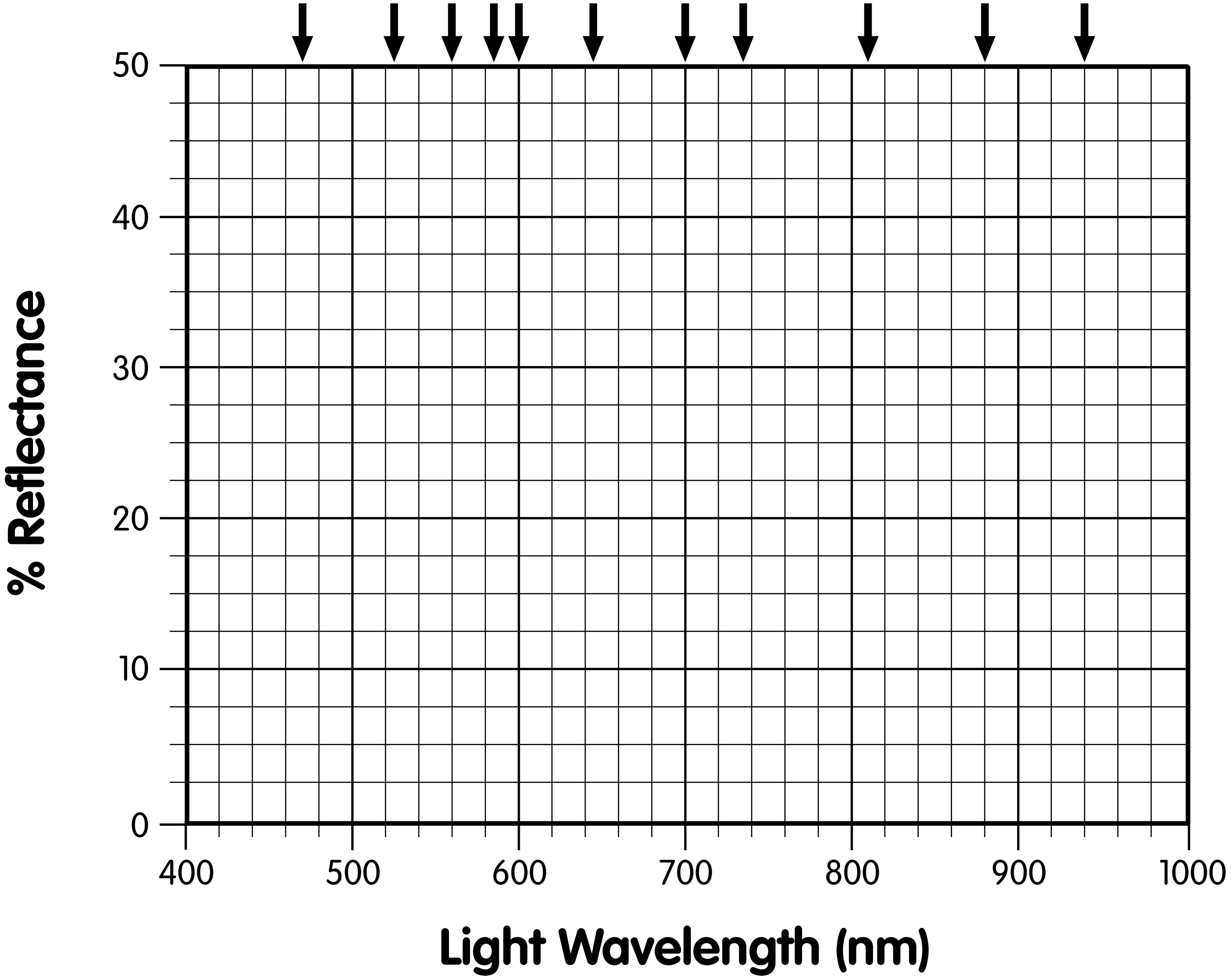
Lesson 3: Graph Template 4.



Lesson 3: Graph Template 5.



Lesson 3: Graph Template 6.



4 Color Vision

Objectives

- ☞ Learn that human color vision is different from machine vision.
- ☞ Learn that human color vision is a complicated response to light.

About this lesson

This lesson explores some aspects of human color vision in contrast to the “machine vision” of the ALTA spectrometer, using the ALTA as a tool to help compare what we perceive with the wavelengths of light that hit our eyes. The students will experiment with human color vision, partly by experimenting with mixes of colors and partly by comparing the eye’s responses to reflectance spectra from the ALTA spectrometer. They will observe that the color we see is not merely a wavelength of light. This lesson assumes that the students have used the ALTA spectrometer; if not, the instructor should incorporate the procedures of Lesson 3. The students should

- ❖ experience that “white” is the eye’s response to a mix of red, green, and blue light;
- ❖ experience that the color yellow can arise from spectrally pure light of wavelength near 585 nm;
- ❖ experience that the color yellow can arise from a mix of red and green light; and
- ❖ experience that yellow can also arise from the absence of blue light.

Materials

- ✔ ALTA spectrometers.
- ✔ Rainbow spectrum chart or apparatus to display rainbow on wall (see Lesson 2).
- ✔ Reflectance standards (pieces of white poster board or thick paper).
- ✔ A variety of yellow materials: poster board, yellow pad paper, bananas, lemons, yellow glitter glued to paper, cloth, flowers, etc.
- ✔ Color television or computer monitor.
- ✔ Hand lenses or magnifying glasses.
- ✔ Data sheet, worksheets, and graph templates (included).

Background

Human color vision is much more complicated than the spectrum of visible light and involves many fascinating issues in psychology, neurology, biochemistry, and culture. For instance, we can see distinct colors that are not part of the rainbow (white, brown, burgundy, rust, visibility orange, day-glow green, etc.); we cannot see color at all under very dim light; and we see mixes of some spectral colors as other spectral colors.

Very simply, the inside of the back of a human eyeball is covered by a layer of light-sensor cells and nerve cells that connect them with each other and eventually with the brain. This layer, called the retina, contains four kinds of light sensor cells: rods and three colors of cone cells. Rod cells are quite sensitive to light and permit us to see in low-light conditions (like at night). They are most sensitive to green light, although they respond to light from violet through orange. The cone cells are less sensitive to light, but respond to different colors: blue, green, and red. The cone cells permit color vision. Signals from the rod and cone cells are processed by the nerves in the retina and then transmitted to the brain along the optic nerves. Parts of the brain process these nerve impulses (in ways that are poorly understood) to produce our color view of the world.

Vocabulary

Color, rods, cones, retina

Essential knowledge

1. Use tools to collect, analyze, and record information.
2. Organize, analyze, evaluate, and make inferences from direct and indirect evidence.
3. Construct graphs, tables, maps, and charts using tools including computers to organize, examine, and evaluate data.
4. Identify uses of electromagnetic waves in various technological applications, such as fiber optics, optical scanners, and microwaves.
5. Demonstrate various wave interactions, including interference, polarization, reflection, refraction, and resonance within various materials.

Procedure

PREPARATION

1. Ensure that the ALTA spectrometers are in working order.
2. Set up a projector to project a rainbow spectrum (Lesson 2).
3. Cut the yellow materials (paper, poster board, etc.) into pieces measuring at least 3" × 5" inches so there are enough to go around.

CLASSROOM PROCEDURE

1. *The color white (mostly demonstration).*
    - (a) Ask students where white is in the spectrum and if white really is a color. Show students the spectrum on the wall as a way of explaining that the many spectrum colors come from the white light of the projector lamp. Draw out the inference that white is the color we see when light of many different wavelengths hits our eyes.
    - (b) Turn on the color TV or computer monitor and tune it so a white field is present. On the computer, open a file that has a white background, like a text document in a word processor. On a TV, turn the brightness and contrast knobs to their maximum limits. Have the students file by the TV and look at the white field with the magnifying glass or hand lens. They will see that the white is actually made up of little bright dots of red, blue, and green.

2. *The color yellow.* Our eyes and brain perceive many combinations of light wavelengths as yellow. This part of the lesson lets the students explore these combinations.

   (a) With the spectrum projector, point out that the yellow part of the spectrum is between orange and green and comes from a very limited range of wavelengths of light, at approximately 585 nm. This is *spectral yellow*, light of a single wavelength that our eyes perceive as yellow. Turn on the yellow lamp of the ALTA spectrometer and show it to the class; this is the same kind of spectral yellow as in the spectrum.

   (b) Turn on the color TV or computer monitor and tune it so a yellow field is present, or change the color tint/hue knobs on the TV so that yellow is visible.

   (c) Have the students file by the TV and look at the yellow field with the magnifying glass or hand lens. They will see that the yellow is actually made up of little bright dots of red and green — the blue dots that they saw with the white field are not lit up.

   (d) Ask the students to predict the spectrum of light that the red dots emit (should end up with lots of red light and little light of other colors). Draw such a spectrum on the template.

   (e) Ask the students to predict the spectrum of light that the green dots emit (lots of green light but little light of other colors). Draw this spectrum on the same template.

   (f) Now, ask the students to predict the spectrum from both the red and green lights. They should suggest what is already on your template — light in green wavelength and light in red wavelengths, but little light in blue, yellow, or orange wavelengths. Remind the class that they see this combination of red and green light as yellow, even though little *spectral yellow* hits their eyes.

   (g) Give each group a yellow object, a piece of white poster board or heavy paper, and an ALTA Reflectance Spectrometer to take their own reflectance spectrum.

   (h) Review how to use the ALTA spectrometer and the importance of standardization.

   (i) Have each group take a standardized reflectance spectrum of the object, as was done in Lesson 3, recording their data on the attached worksheet. Students can use either the “simple” or “better” calculations.

   (j) Have each group graph their standardized reflectance spectrum on a copy of the template graph.

   (k) Compare the graphs among the classroom groups. Most of the graphs will show yet another way of making yellow — by the absence of blue. These materials (most papers and fabrics, particularly) will show fairly high reflectance values from infrared through yellow, perhaps slightly lower green reflectance, and much lower blue reflectance. As a “real-world example,” show the class the reference reflectance spectrum of a yellow-colored bruise. Compared to the surrounding pale skin, the bruise is yellow because it absorbs more blue light.

3. *Discussion.* List with your students the ways that light can enter our eyes to make the color yellow.

Extensions

1. To learn more about color vision, consult the following sources.
    - 🕮 “The Case of the Colorblind Painter” in *An Anthropologist on Mars* by Oliver Sacks, 1995, Borzoi Books.
    - 🕮 “The Colors of Things” by Phillipe Brou et al., *Scientific American*, Sept. 1986, pp. 84–91.
    - 🕮 “The Retinex Theory of Color Vision” by Edwin Land, *Scientific American*, Feb. 1977, pp. 108–128.
    - 🕮 “The Genes for Color Vision” by Jeremy Nathans, *Scientific American*, Feb. 1989, pp. 42–49.
2. Impressionist, post-impressionist, and “pointilliste” painters used small dots of color to represent textures and colors in their work. Examine some of their works (e.g., Seurat, Cassat) and see how they have used the peculiarities of human color vision in their work.
3. Discuss how ophthalmologists and optometrists use technology to diagnose vision problems. Talk about what kinds of careers are available in the field of vision correction.
4. Discuss how the perception of color changes our emotions about a place. An example is fast-food restaurants, which are often decorated in orange and red colors to make people feel unsettled.
5. Discuss how artists of different eras have used color to convey emotion, size, and distance.
6. Use a model of the eye to explore the optics of human vision. Compare this with insect vision, by using a plastic “insect” eye lens to show a representation of compound eye vision.

Lesson 4: Data Sheet 1.

Class: ______________________________ **Date:** ______________

Scientist(s): ____

____

		Dark Voltage (mV):			
		Voltage (mV)			
Color	**Light Wavelength**	**Yellow #1:**	**Standard: White Paper**	**Yellow #2:**	**Yellow #3:**
Blue	**470 nm**				
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**				

Lesson 4: Worksheet for Calculating Reflectance.

(Simple)

Class: ______________________________ Date: ______________

Scientist(s): ____

____

		Voltage (mV)		% Reflectance
Color	Light Wavelength	Yellow Object:	Standard: White Paper	(Sample Voltage ÷ Standard Voltage) × 100
Blue	470 nm			
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			

Lesson 4: Worksheet for Calculating Reflectance.

(Better, but more complicated)

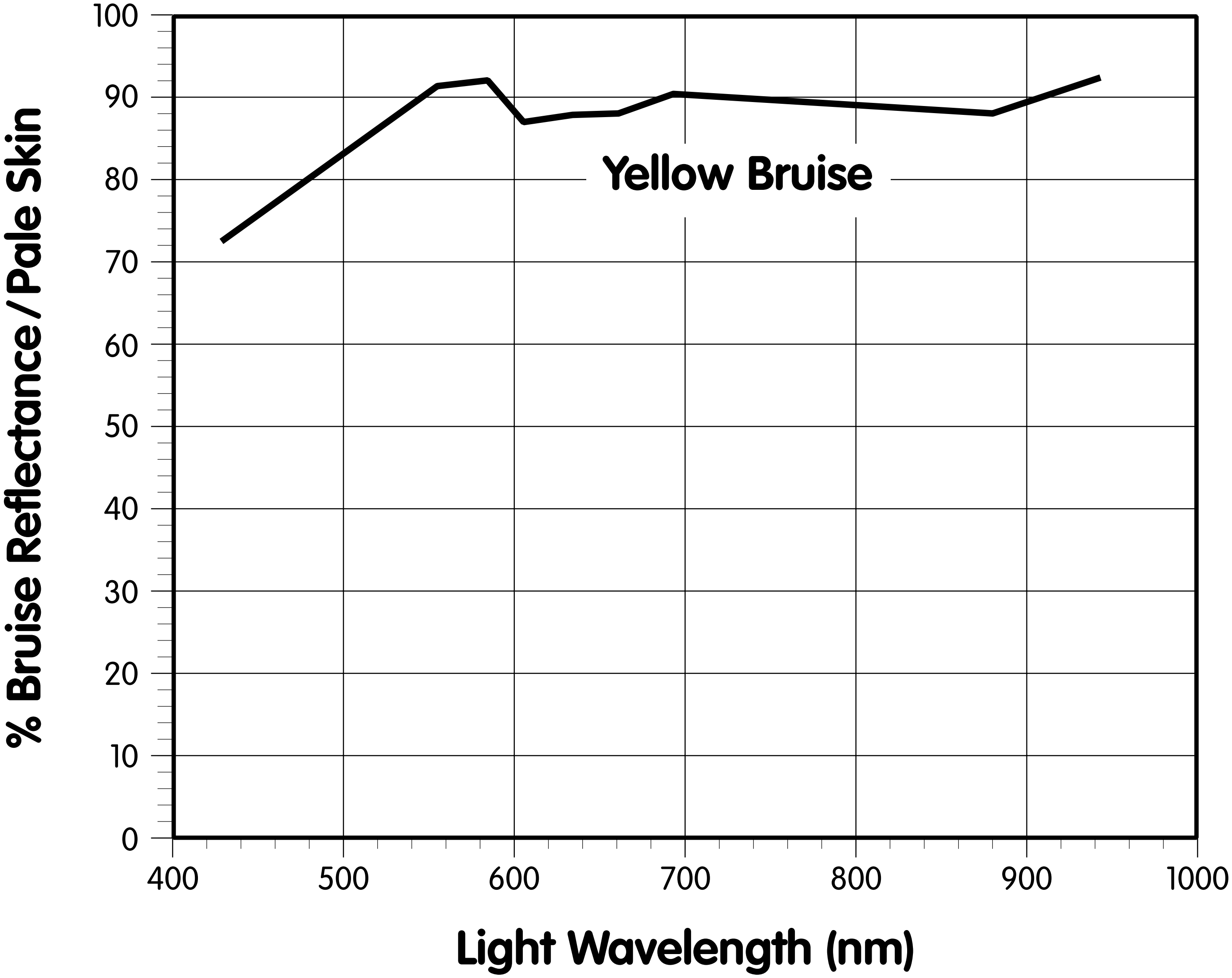
Class: ______________________________ Date: ______________

Scientist(s): ____

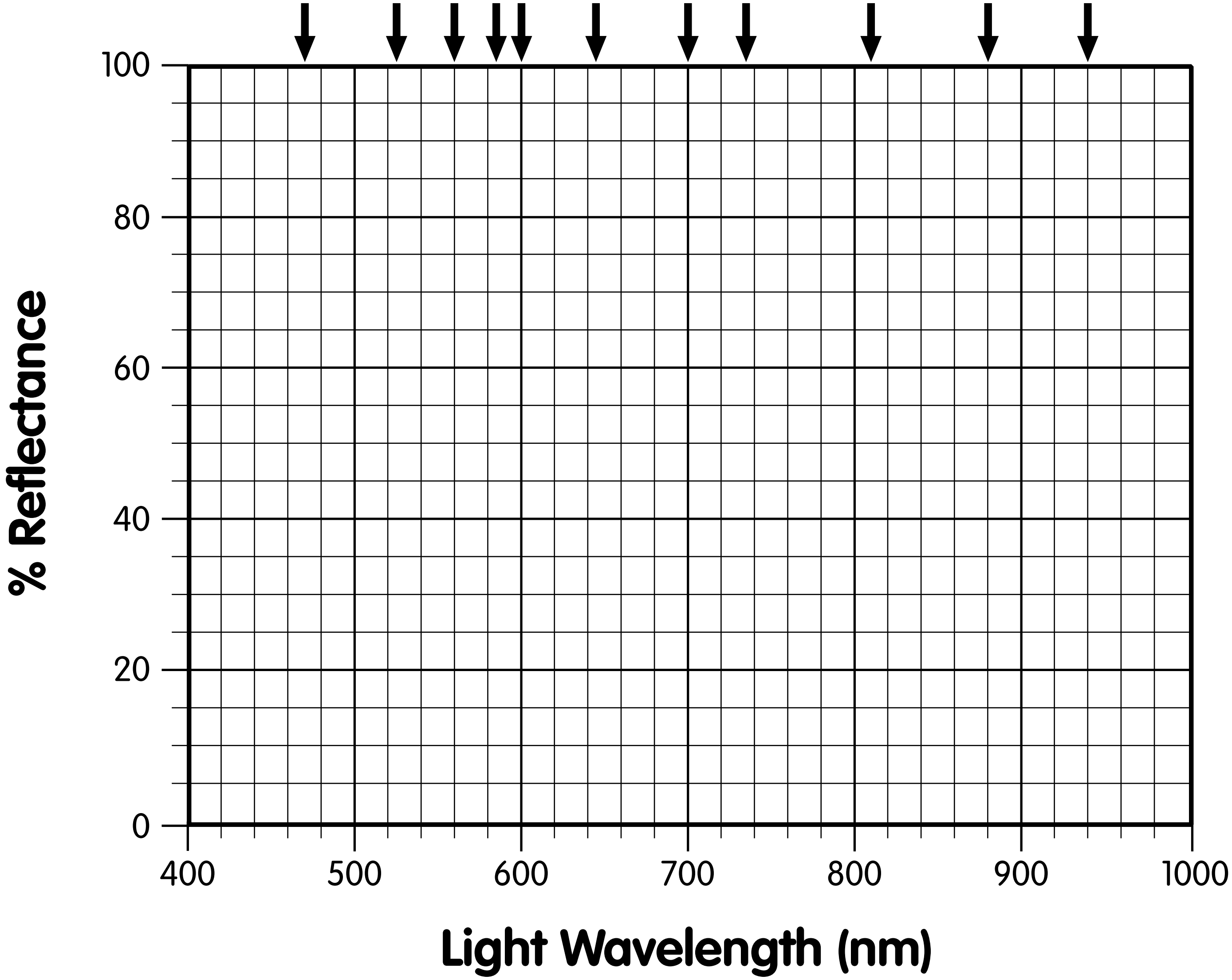
____

		Dark Voltage (mV):		
		Voltage (mV)		% Reflectance
Color	Light Wavelength	Yellow Object:	Standard: White Paper	$\left[\frac{(\text{Sample Voltage} - \text{Dark Voltage})}{(\text{Standard Voltage} - \text{Dark Voltage})}\right] \times 100$
Blue	470 nm			
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			

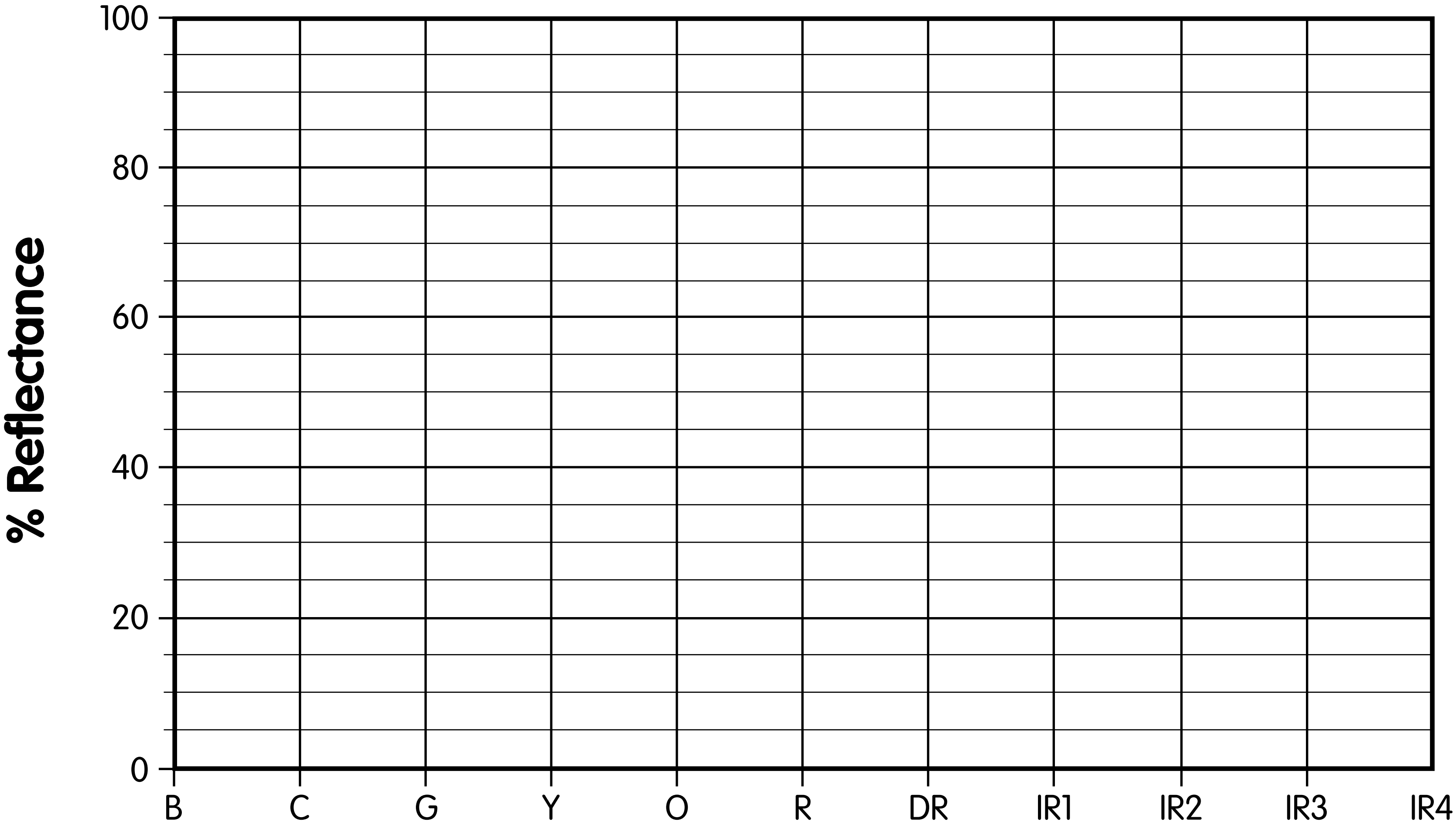
Lesson 4: Reference Graph.



Lesson 4: Graph Template 1.



Lesson 4: Graph Template 2.



LESSON

5

ENVIRONMENTAL SCIENCE

Remote Sensing and Earth Observations

Objectives

Students will understand some of the interpretations and uses of Earth observation imagery (as from LANDSAT and SPOT satellites) by

☞ taking reference “ground truth” reflectance spectra of common land surface covers;

☞ learning the importance of near-infrared spectral bands in Earth observations; and

☞ experimenting with false-color infrared imagery.

About this lesson

Images of Earth from space have had a profound influence on the way people think about our home planet. From those high vantage points, it’s easy to understand the interconnections among land, ocean, air, and life. Views from the “high ground” of space are now essential to understanding Earth’s environments and humanity’s effect on them. Our views from space come mostly from Earth observation satellites, which now include a huge range of sensors that let us observe weather, water in the atmosphere, vegetation, heat emissions, ocean temperature, ocean topography, and even military targets.

In this lesson, students will explore the reflectances of many types of land surface covers, as “ground truth” for interpretation of satellite imagery. This lesson can provide a strong background for interpretation of spacecraft imagery, especially of false-color imagery, that could be used in a broad range of environmental studies.

This lesson assumes that the students have used the ALTA spectrometer; if not, they should start with Lesson 3.

Materials

✔ ALTA spectrometers.

✔ Vegetation materials: grass, deciduous leaves, and conifer needles.

✔ Surface cover materials, like dirt, asphalt, concrete, and roofing shingles.

✔ False-color imagery from a spacecraft or airplane (not included here), possibly from a textbook.

✔ Data sheet, worksheets, and graph templates (included).

✔ Calculators (optional).

Background

Most sensors in Earth observation satellites are *imaging spectrometers,* which means that they collect images or photographs of the Earth’s surface in a number of different light wavelengths. Imaging spectrometers are like color video cameras or TV cameras. When light from a scene enters a video camera, the camera measures the intensity in each of three colors (red, green, and blue) that comes from each spot in the image. Each spot in the image is called a *pixel*, which is short for picture element. The intensities of the colors for each pixel are converted into digital electronic signals, which are then sent to a TV monitor or recorded onto videotape or disks.

An imaging spectrometer acts like a video camera in that it isn't limited to visible light or to three colors. For instance, the LANDSAT satellites have an imaging spectrometer called TM (for thematic mapper) that records three wavelength bands of visible light and four bands of invisible infrared light. For each spot in the scene (each pixel of the final image), TM measures the intensities of light in these seven wavelength bands. Besides LANDSAT TM, there are many other satellites and sensor systems used in remote sensing. Table 1 shows how the ALTA Reflectance Spectrometer wavelengths compare to the color bands of some of these imaging spectrometers.

The data from an imaging spectrometer is stored (in a computer) as a digital image, and it can be shown in colors that are different from those in the original scene. For instance, you could take the intensities of red light and show them as blue on your computer screen or paper. This type of image, with colors deliberately changed, is called *false color.*

False color is an important way of representing the brightness of infrared light, which of course does not have visible colors. Probably the most familiar type of false-color image shows a near-infrared wavelength (like 880 nm) as red, real red as green, and real green as blue. Real blue is not shown, and appears black. This false color is useful because vegetation is very reflective (bright) in near-infrared wavelengths (as was shown in Lesson 3 and will be repeated here).

Vocabulary

Spectrometer, imaging spectrometer, remote sensing, pixel, deciduous, conifer, multispectral, false color, LANDSAT, ground truth

Procedure

PREPARATION

1. Work through the classroom procedures beforehand — as in Lesson 3.
2. Collect leaf and other surface cover materials for reflectance spectra.
3. Photocopy data table and graph templates.
4. Check that all spectrometers are in working order and have batteries.
5. Ensure that calculators are available.

CLASSROOM PROCEDURES

1. *Different leaves.* Following the procedures of Lesson 3, have the students take ALTA reflectance spectra of different types of vegetation, including, at a minimum, a deciduous leaf, green grass, and conifer needles (pine, fir, or spruce). Arrange masses of the grass blades and conifer needles so they completely cover a black surface and use the ALTA on the masses of blades or needles. Have the students record their data (including dark voltage), calculate reflectances, and graph the reflectances of the different types of leaves on a single graph. What are the differences among the reflectance spectra of different leaf types? Are there any clues in the visible colors of the leaves that would hint at the differences in their infrared reflectances? For each of the leaf types have the students prepare a bar graph showing reflectances of the leaves in the wavelength bands that LANDSAT TM would see (Table 1). How could you use the results to distinguish different ground covers from orbit,

such as a grass farm from a Christmas tree farm from a woodlot? Why might leaves have different colors? How might a plant benefit by having dark leaves rather than light-colored leaves? [LANDSAT TM images and other multispectral images can be seen on the Internet at http://www.spaceimage.com/home/gallery/index.html and http://svs.gsfc.nasa.gov/imagewall/LandSat.html among many others.]

2. *Other surface covers.* Following the procedures of Lesson 3, take ALTA reflectance spectra of dirt, common rocks, asphalt, concrete, and roofing shingles. Have the students record their data (including dark voltage), calculate reflectances, and graph the reflectances of the different types of materials on a single graph. What are the differences among the reflectance spectra of these different surface covers? What wavelengths of light are best for distinguishing these types of surface cover? What wavelengths of light are best for distinguishing living plants from these "mineral" surface covers? For each of the surface types, have the students prepare a bar graph showing reflectances of the surfaces in the wavelength bands that LANDSAT TM would see.

3. *False color.* Studies of vegetation, crops, and land cover typically use a false-color representation of the scene where reflectance in the near-infrared light (880 or 940 nm) is shown as red, while green and blue reflectances are shown as green and blue. In this false-color set (or transformation), what colors would the leaves and other ground cover appear to have? How would they look in this transformation: 430 nm as red, 635 nm as green, 880 nm as blue?

Extensions

1. *Remote sensing — false color.* Some animals can see in near-infrared light (like 880 nm wavelength). If you could see this near-infrared light as a separate color (call it "jale," as in the classic fantasy book *A Voyage to Arcturus* by David Lindsay), what would the world look like? What colors would leaves be? What colors would other objects be? Draw a picture of a tree (or other object), making the parts that reflect near-infrared light in sparkly colors (crayons). For instance, if an object reflects lots of red and near-infrared light, you would draw it as sparkly red.

2. *Global warming/local weather.* In the summer, you've probably noticed that it is cooler in the shade of a tree than it is on concrete or asphalt. Also, you may have noticed that it is hotter in a city than outside the city in fields and forests. Part of these temperature differences comes from how much light is absorbed by leaves compared to concrete, asphalt, roof shingles, etc. For each of the leaf and surface cover types, calculate the average light reflectance (in visible and near-infrared light). On average, do leaves reflect more or less light than other cover types?

   What happens to the energy in the light that is absorbed? To find out, do the quick experiment of placing pieces of black and white construction paper in the sun (or under a bright lamp). After 15–30 minutes, feel how hot they are. What does this discovery suggest about why cities tend to be hotter than the farms and forests around them?

3. *Ages of leaves — the red shift.* Leaves change color as they age, and this change can be used to tell (from a satellite in orbit) how quickly crops are maturing. Collect new, mature, and dying leaves from a plant (or plants). Take ALTA reflectance spectra as in Exercise 3, and graph the results on a single chart. What are the differences? Often, the reflectance at about 700 nm (barely red) shows the most change. Is this the case for your leaves? This change (if you see it) is supposed to come from changes in the chlorophyll molecules in the leaves (old chlorophyll does not absorb the same wavelengths of light as new chlorophyll).

TABLE 1. ALTA color bands and imaging spectrometer equivalents.

		Approximate Equivalents			
ALTA Color	**Wavelength (nm)**	**LANDSAT 1–3 MSS**	**LANDSAT 4,5 MSS**	**LANDSAT 4,5 TM**	**SPOT**
Blue	470				
Cyan	525			Band 1	
Green	560	Band 4	Band 1	Band 2	Band 1
Yellow	585				
Orange	600				
Red	645	Band 5	Band 2	Band 3	Band 2
Deep Red	700				
IR-1	735	Band 6	Band 3		
IR-2	810			Band 4	Band 3
IR-3	880				Band 3
IR-4	940	Band 7	Band 4		

Lesson 5: Data Sheet 1.

Class: ______________________________ Date: ______________

Scientist(s): ____

____

		Dark Voltage (mV):			
		Voltage (mV)			
Color	Light Wavelength	Leaf 1:	Standard: White Paper	Unknown 2:	Unknown 3:
Blue	470 nm				
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				

Lesson 5: Worksheet for Calculating Reflectance.

(Simple)

Class: ______________________________ Date: ______________

Scientist(s): ____

____

		Voltage (mV)		% Reflectance
Color	Light Wavelength	Sample:	Standard: White Paper	(Sample Voltage ÷ Standard Voltage) × 100
Blue	470 nm			
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			

Lesson 5: Worksheet for Calculating Reflectance.

(Better, but more complicated)

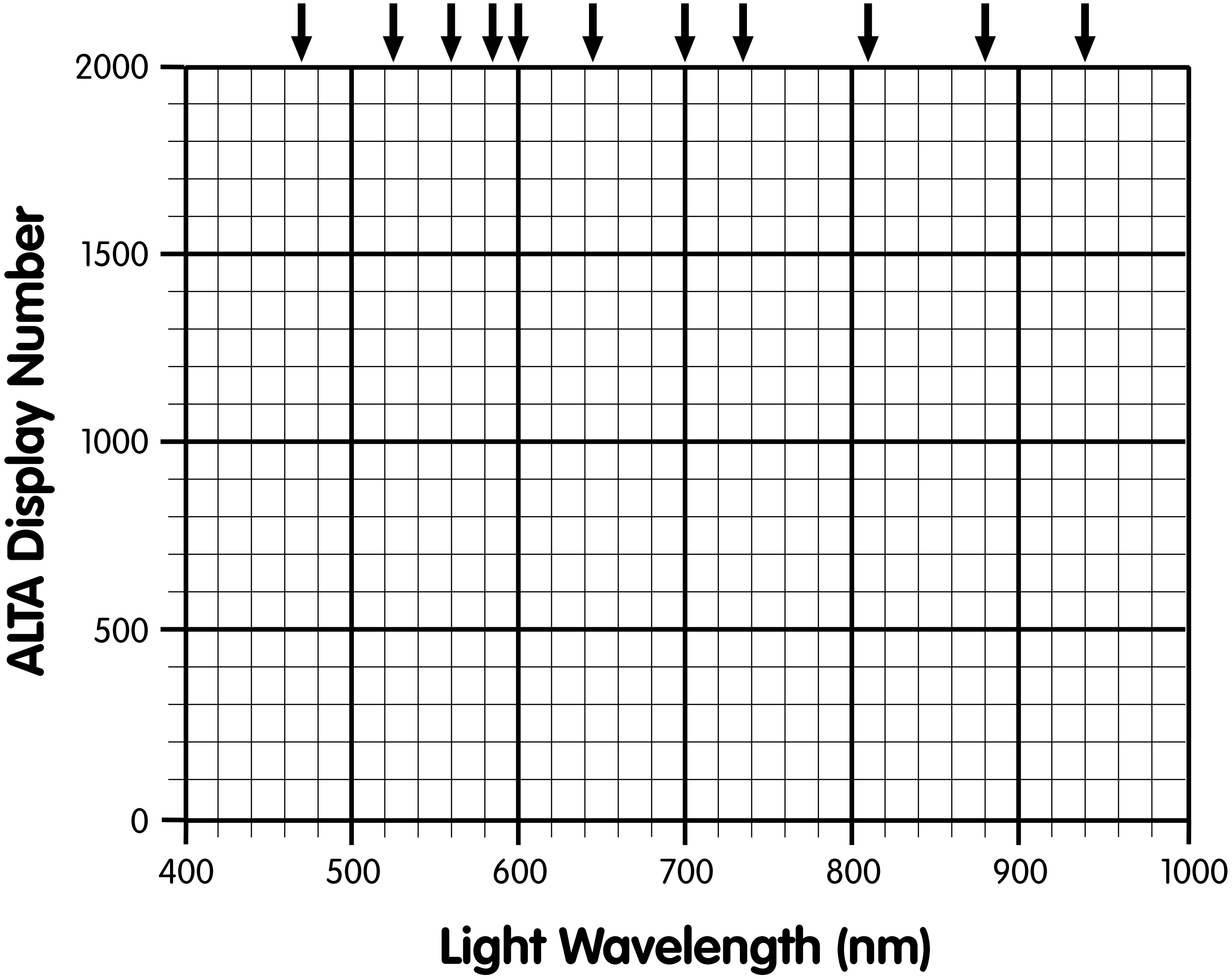
Class: ______________________________ Date: ______________

Scientist(s): ____

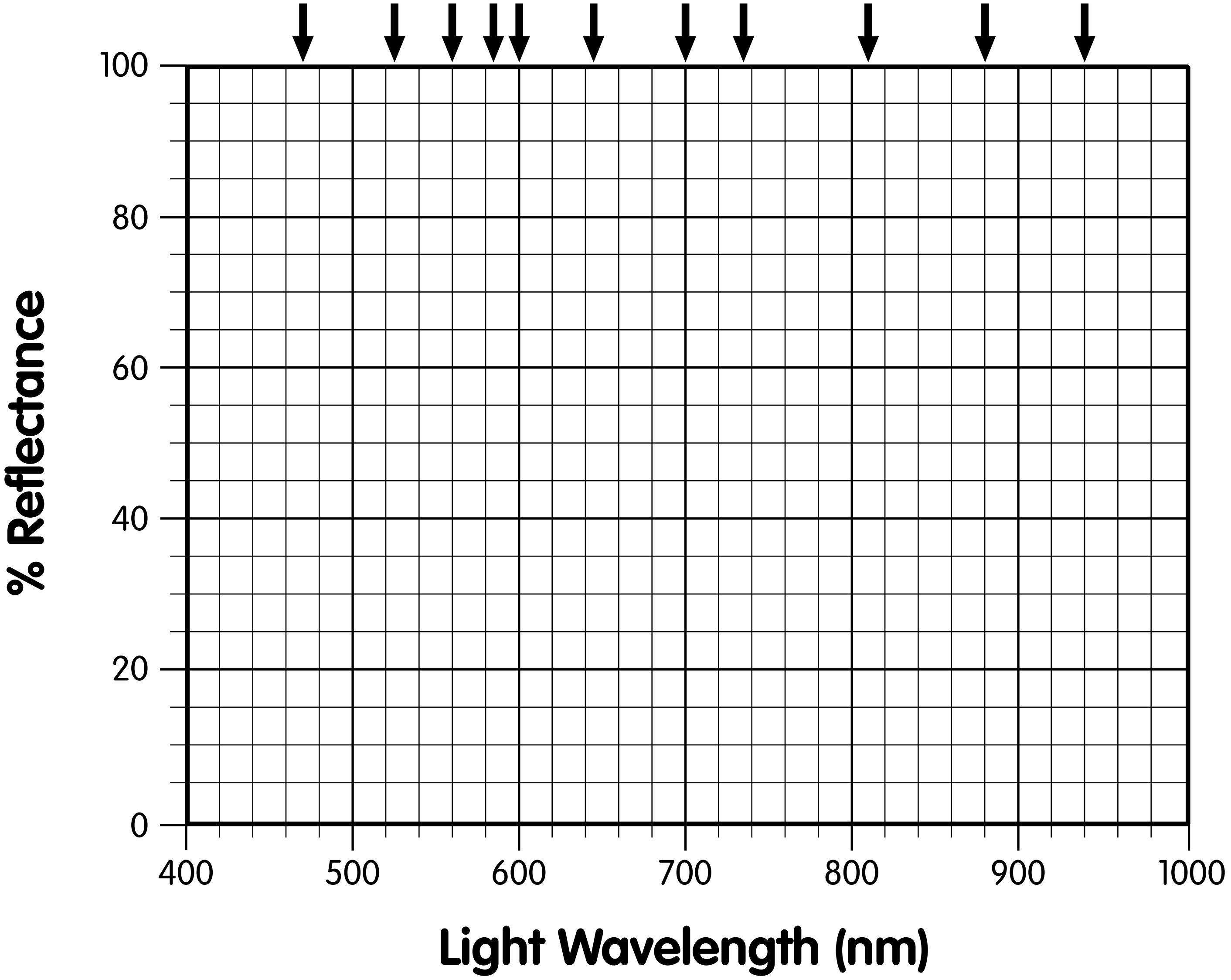
____

		Dark Voltage (mV):		
		Voltage (mV)		% Reflectance
Color	Light Wavelength	Sample:	Standard: White Paper	$\left[\frac{\text{(Sample Voltage – Dark Voltage)}}{\text{(Standard Voltage – Dark Voltage)}}\right] \times 100$
Blue	470 nm			
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			

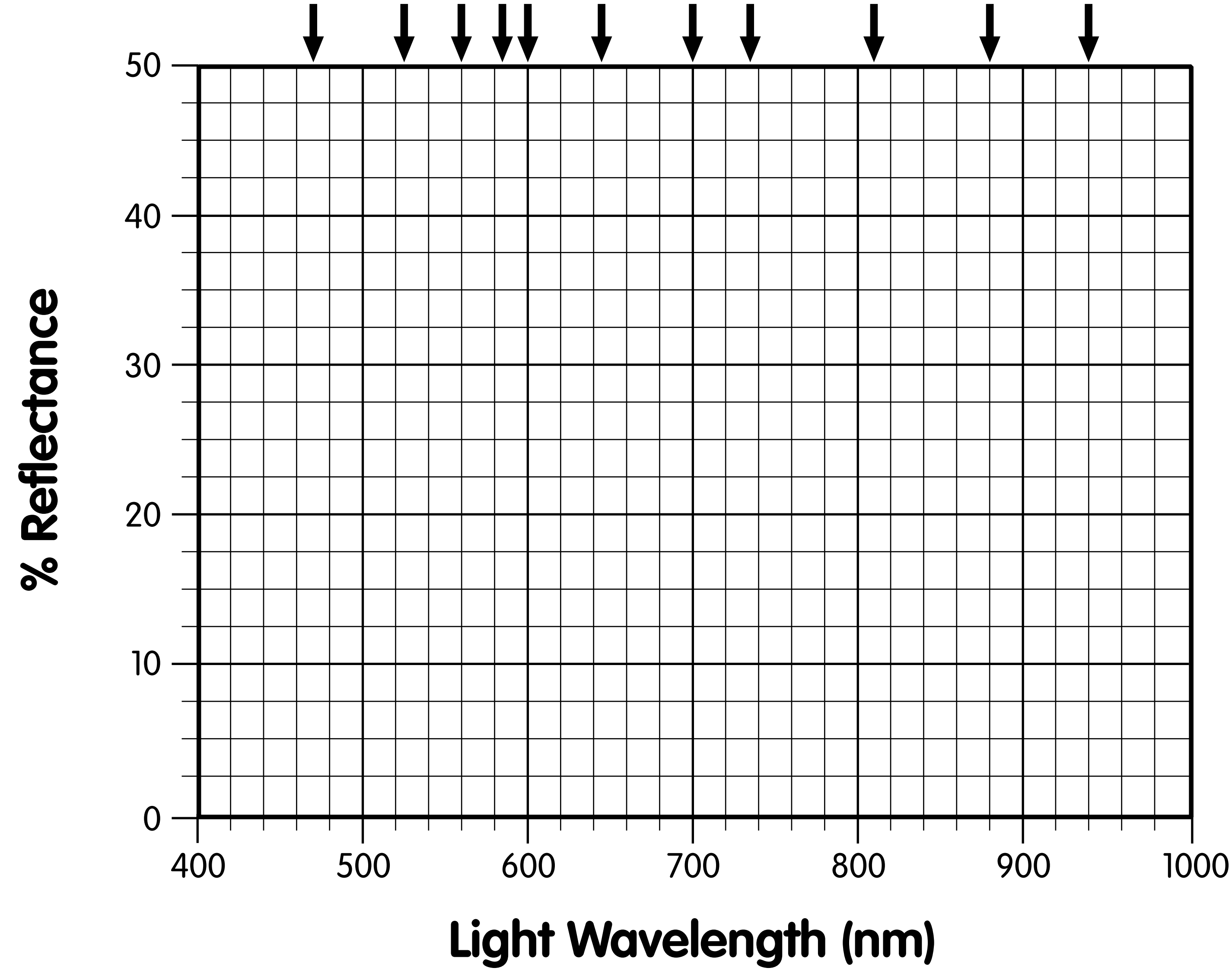
Lesson 5: Graph Template 1.



Lesson 5: Graph Template 2.



Lesson 5: Graph Template 3.



Soil Moisture

Objectives

- ☞ Develop laboratory standard spectra for a soil with differing water contents.
- ☞ Experience the variability of repeated measurements of a physical quantity.
- ☞ Calculate the water content of real soil.
- ☞ Track the water content of real soil through time on a diurnal or longer basis (optional).
- ☞ Understand how aircraft and orbital remote sensing can measure soil moisture and thereby predict crop success or failure.

About this lesson

In this lesson, the students will gain hands-on experience in the remote measurement of soil water content. This remote sensing measurement, done from aircraft or satellite, is one of the common predictors of crop success and so has widespread and important environmental value. The students will measure the reflectance spectra of a single soil sample at various moisture levels, compare the spectra, and generalize from these a tool for using reflectance spectra as a measure of soil moisture. This lesson assumes that the students have used the ALTA spectrometer in previous lessons.

Materials

- ✔ ALTA spectrometers.
- ✔ Balances (three bar or other kind) to measure weights from 0.1 to 100 grams.
- ✔ Access to an oven.
- ✔ A mass of a soil, about 1 kilogram (2 pounds). Ideally, the soil should be fine-grained and homogeneous in color and texture, and should be taken from a site near the classroom so students can measure the same material in place.
- ✔ Small cups or glassware to weigh water in.
- ✔ Graph templates (included).

Background

Soil moisture is one of the prime predictors of crop growth and success. As a result, there has been considerable effort to use satellite imagery to understand soil moisture and predict crop success. This effort aims not only to assist farmers, but also to assist grain traders and speculators.

Vocabulary

Diurnal, remote sensing, soil humidity, dehydrate

Essential knowledge

1. Analyze and interpret information to construct reasonable explanations from direct and indirect evidence.
2. Communicate valid conclusions.
3. Collect data.
4. Construct graphs, tools, tables, maps, and charts using tools, including computers, to examine, organize, and evaluate data.
5. Collect, record, and analyze information using balances, thermometers, and calculators and extrapolate from collected information to make predictions.

Procedure

PREPARATION

1. Collect samples of a soil (dirt), preferably from near the classroom so the students can visit it to take spectra in place (i.e., without moving the soil). Collect about a kilogram (~2 pounds), or enough for 10 samples of ~50 grams each with plenty left over, and spread it out to dry for a day or two on trays inside your classroom. After drying, the soil should be crumbly or sandy, and should not ooze water when squeezed. Put the dried soil in a watertight container for use in class.
2. Measure current soil humidity (this can be done ahead of time or as part of an extended lab exercise in class). Take a sample of the dried soil (~50 grams), weigh it, and record the weight. Put the sample in the oven, spread out in an aluminum pie pan or other surface, and bake it at ~300°F for an hour. This will dehydrate the soil (well enough for this exercise). Let it cool, and reweigh it. The weight loss is all water. The percentage weight loss from the original is the percentage of water in the original soil; soil water is commonly 5–20% or so (desert soils have much less water, of course). This soil moisture content will be used in your students' calculations. Save the dehydrated soil in a watertight container to measure its reflectance spectrum.
3. Locate and collect satellite or airplane images of farmland that show variations in the color of the soil (image from a remote sensing or agriculture book or journal). The local agriculture extension agent may be able to help in securing these materials.

CLASSROOM PROCEDURE 1: DATA COLLECTION

1. Review the procedure: Each student/group will weigh their soil sample and take a standardized reflectance spectrum of it. Then, each group will add a different amount of water to their sample, mix it thoroughly, and again take a standardized reflectance spectrum. Using the water content of the base soil, each group will calculate the water content of their mixed soil. All the groups will compare their results and graph reflectance versus soil moisture content for each wavelength.

2. (Optional.) Have students collect the soil and spread it out for drying, as in “Advance Preparation 1” above. Have students dehydrate a sample of the soil and calculate the moisture content of the dried soil, as in “Advance Preparation 2” above.
3. Distribute the dried soil to students/groups, in masses of about 50 grams each.
4. Have each student/group obtain and calculate a standardized reflection spectrum for their soil sample.
5. Have each student/group add a different amount of water to their soil sample — e.g., 0.5 gram for group 1, 2 grams for group 2, etc.
6. Each should mix the water thoroughly into their soil sample and obtain a standardized reflectance spectrum of the moistened soil.
7. Each group should, using the percentage of water in the dried soil, calculate the percentage of water in their moistened sample.

CLASSROOM PROCEDURE 2: DATA MANIPULATION

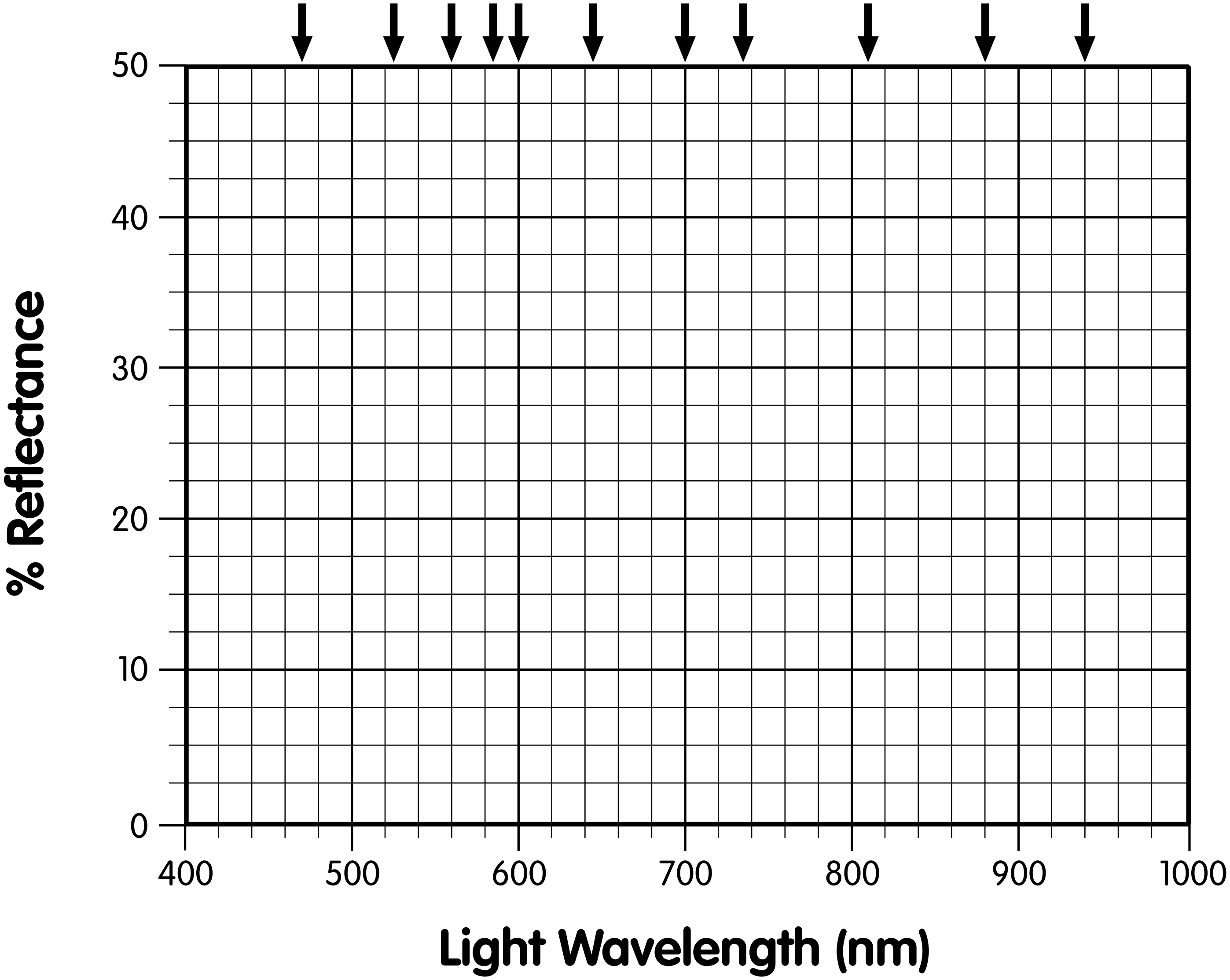
1. *Reproducibilty of a measurement.* Each of your groups has obtained a reflectance spectrum of the same dried soil. Compare the reflectance measurements of all the groups. Even though they measured the same material, they will undoubtedly have slightly different results. Discuss why the results might not all be the same. (Possible mathematical manipulations of these data are suggested under Extensions.)
2. *Soil brightness vs. wavelength and water content: best light wavelength.* On a single graph on the board or overhead, plot each group’s data reflectance spectrum for their moistened soil (horizontal = wavelength, vertical = reflectance; Graph Template 1), and label each as to its percentage of water (a template is supplied). At which wavelength(s) does the reflectance of the soil change the most as its water percentage changes? (In other words, which wavelength of light shows the greatest difference in brightness between wet and dry soils?) Does a single wavelength show the most change over the whole range of water percentage, or does reflectance at some wavelength change a lot with the driest soils, but little for wetter soils?
3. *Calibration of soil water.* Select the wavelength of light where reflectance changes the most with changing water content. For that wavelength alone, collect the groups’ data and make a graph of reflectance in that wavelength (vertical) vs. percentage of water in the soil (horizontal). A Graph Template 2 is supplied. Describe how the brightness at that wavelength varies with water content (increases or decreases? linear or not?). This graph is your laboratory calibration of soil moisture in your chosen soil.
4. *In-place measurement.* Take the class and spectrometers out to the site where you collected the soil sample. Have the students take reflectance spectra of the soil in its place on the ground. Referring to their calibration graph constructed in the laboratory (part 3 above), what is the water content of the soil in place?
5. *Comparison with remote sensing.* Show the class images of farmland with variations in the color of the soil (image from a remote sensing or agriculture book or journal). How would they use images like this to estimate the water content of soil? How would they use imagery like this to plan what crops to plant? How would they use it to know when to plant the crops?

Extensions

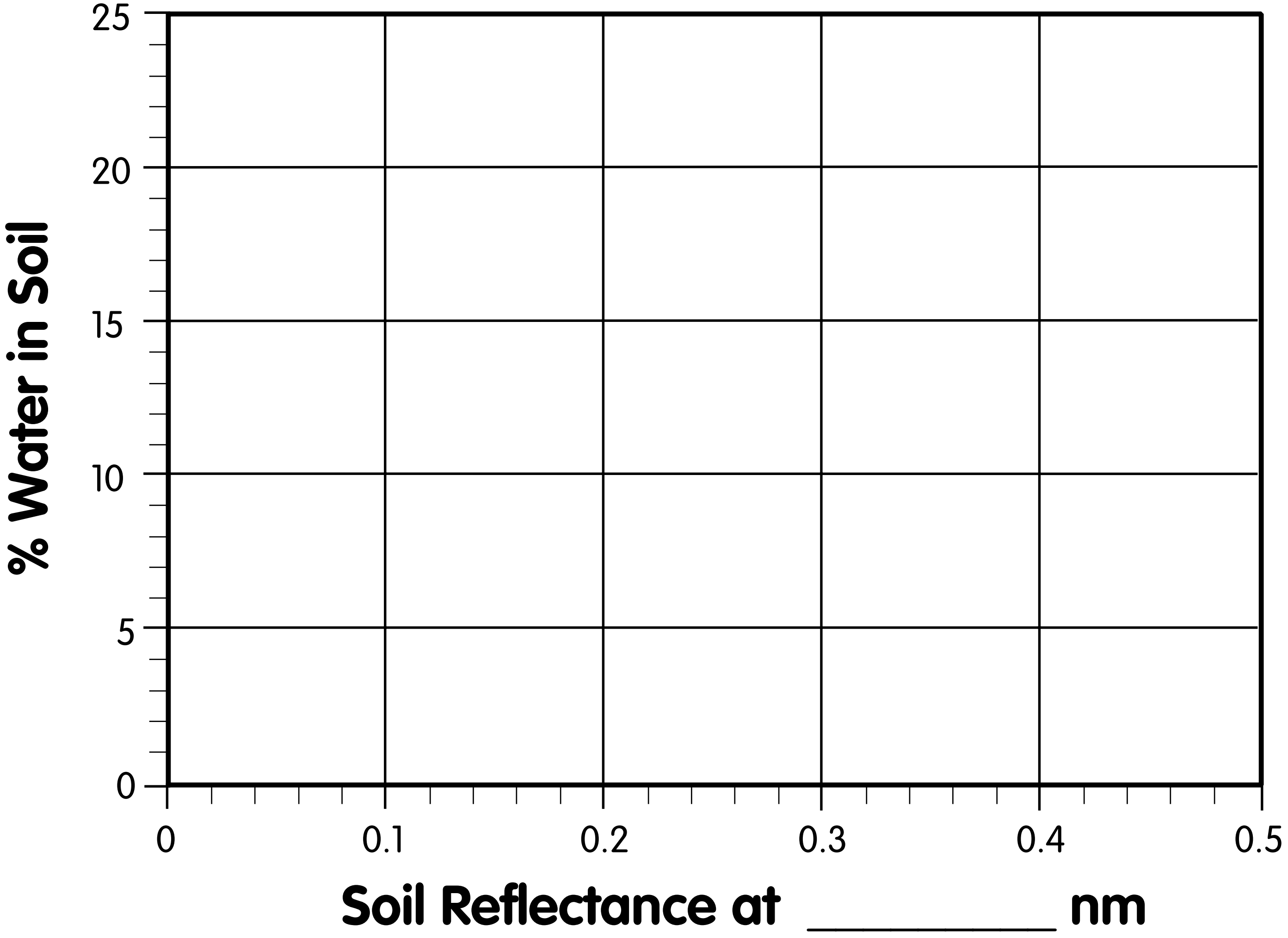
1. *Reproducibility of measurements — laboratory precision.* Each student group will have produced a reflectance spectrum of the common dried soil, and these reflectance measurements can be treated as a statistical sample. Students can calculate means and variances (standard deviations) for each wavelength, investigate why the measurements might vary from group to group, and question why some wavelengths have greater variances than others.

2. *Daily variation in soil water content.* Take spectra of the soil in place as the day progresses. Graph the individual spectra. Using the soil water calibration chart, calculate the water content in the soil for each individual spectrum. Graph these results as percentage of water in soil (vertical) vs. time of day (horizontal). Why does the water content change? Does it matter if the soil is shaded? Does it matter when the sunlight hits the soil? What if the ground is watered?

Lesson 6: Graph Template 1.



Lesson 6: Graph Template 2.



LESSON

7

ENVIRONMENTAL SCIENCE

Water Turbidity

Objectives

- ☞ Learn about turbidity as a measure of water pollution.
- ☞ Learn how water turbidity is measured by the standard EPA method.
- ☞ Learn about interferences to physical measurements.

About this lesson

This lesson is a demonstration of measuring water turbidity, using a model of the standard method defined by the U.S. Environmental Protection Agency. It can be adapted for use by small groups, but is presented as a demonstration because it requires a large volume of water and careful control of room lighting. The precise control of room lighting is a good lesson on the importance of careful experimental conditions — without careful controls, variations in room lighting can skew the data you want to measure. Here, the ALTA is used only as a light meter; its own colored lamps are not used. This lesson assumes that the students are acquainted with the ALTA spectrometer; if not, the instructor should integrate the classroom procedures of Lesson 3.

Materials

- ✔ ALTA spectrometer.
- ✔ Fish tank or large bottle with straight sides at right angles to each other.
- ✔ Flashlight or lamp with a well-focused beam.
- ✔ Cardboard box, covered on the inside with black paper (large enough to fit over the ALTA, fish tank or bottle, and lamp), cut with a viewing port so students can see. (See Fig. 2. below.)
- ✔ Several gallons of water.
- ✔ Several cups of skim or powdered milk.
- ✔ Measuring spoons.
- ✔ Data sheet and graph template (included).

Background

An important measure of water quality is its *turbidity*, or the amount of small particles suspended in the water. The particles could be dirt, clay, or other mineral materials, which might make the water look nasty and taste bad. The particles might be little drops of oil, like an emulsion, which would probably make the water dangerous to drink. Or the particles might be algae or bacteria, which would very likely make the water dangerous to drink. Measuring water turbidity is also important for other uses of water — the particles in turbid water hurt machinery by clogging small pipes, sticking to the insides of boilers, and wearing down water pumps.

There are many ways to measure water turbidity, but the standard method recommended by the U.S. Environmental Protection Agency relies on the fact that light is scattered by particles in water. The more particles are present, the more light is scattered. The standard method, which we replicate here, involves shining a beam of light into water, and detecting how much of its light is scattered into a detector aimed at right angles to the light beam.

Vocabulary

Scatter, turbidity, nephelometry, emulsion

Procedure

PREPARATION

1. Set up the fish tank (bottle), lamp, and spectrometer as shown in Fig. 1. The lamp should shine straight into the fish tank along its long end. The ALTA should be placed near the lamp end of the fish tank, with its light entry hole (on the bottom) at the same level as the light beam from the lamp. In this way, light from the lamp that scatters from particles in the water can enter the ALTA and be detected. The lamp and ALTA should be held firmly in place against the fish tank glass (use small boxes, books, and tape), because moving the light beam or the ALTA will affect the measurements.

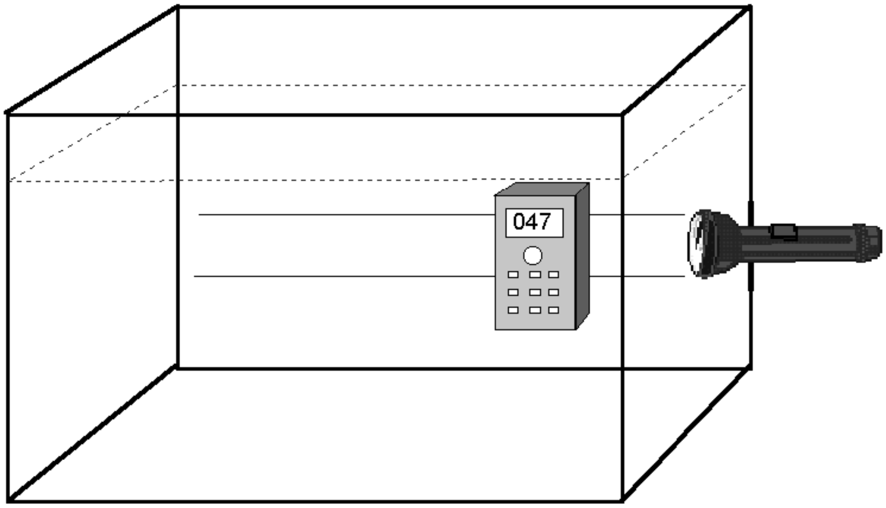


Fig. 1.

2. Ensure that the cardboard box lined with black paper fits over the fish tank, lamp, and ALTA (Fig. 2). The cardboard box is a shield to keep room light out as much as possible.
3. Follow the classroom procedures.

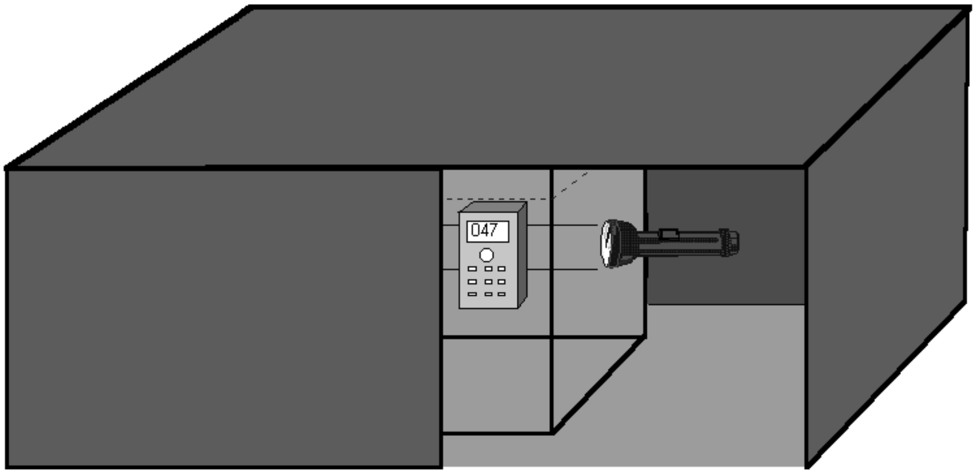


Fig. 2.

CLASSROOM PROCEDURE 1: DATA COLLECTION

1. *Before the lesson.* Fill the tank with a measured amount of clean water and write that amount in the data sheet. Turn down the room lights.
2. *Background Measurement 1.* With the room lights low, turn the ALTA on, but leave the lamp off. Record the display number on the data sheet. This number includes the dark voltage of the ALTA plus a response to the room light that gets into the box and around to the ALTA's light sensor. Have students and objects move around the room a couple of times and record the ALTA display number each time, to see how sensitive the experimental setup is to the positions of people and things. The number should change a lot as shadows fall on the ALTA and as light reflects into the ALTA.
3. *Background Measurement 2.* Place the cardboard box over the tank, ALTA, and lamp. Keep the lamp off and the ALTA on. Record the ALTA number on the data sheet. Have a student stand in front of the box's opening, and see if the display number changes — it likely will because the student will either block out light from the room or reflect light into the box. Record display numbers with students at various places around the room, to see how sensitive the experimental setup is to the positions of people (and things) in the room. Decide on standard places for people and things that will be repeated in each of the following steps.
4. *Background Measurement 3.* With students and objects in their standard positions, turn on the lamp and record the ALTA display number on the data sheet. This is the response of the system (ALTA, lamp, and box) to clear water; it is higher than the background of part 2 because some light from the lamp reflects around in the tank and box and eventually into the ALTA.
5. *Turbid water.* Add a teaspoon (a few milliliters) of milk to the fish tank and stir until mixed. With all people and things in their standard positions, record the amount of milk added and the ALTA display number. Repeat this procedure, adding milk and recording the number. If teaspoons seem to go too slowly, feel free to add more at a time. Continue adding milk and recording data until you cannot see through the tank.

CLASSROOM PROCEDURE 2: DATA MANIPULATION

1. *Interferences.*
   (a) Compare the ALTA readings you took for Background Measurements 1 and 2. On average, are backgrounds 1 or 2 higher? Was the cardboard box useful in blocking out room light?

   (b) What was the range for Background Measurement 2, from highest to lowest? What was the range of ALTA readings for milky water (from part 3 above)? How much milk in the tank would it take to give the same number as the highest background measurement from part 1? From part 2? So, how important was it to have blocked out room light and to have controlled shadows and reflected light from the room?

2. *Turbidity.*
   (a) On the data sheet, subtract the Background Measurement 3 (lamp on, everyone and everything in standard position) from each of the ALTA measurements of milky water. Write these differences in the proper column on the data sheet. These numbers are measurements of how much light scattered from the milk in the water into the ALTA.

   (b) On the data sheet, fill in the column "Cumulative Quantity of Milk." Be careful to convert all your measurements to the same units. For higher math levels, also fill in the column "Concentration of Milk," in units like "teaspoons milk per gallon water" or "liters milk per liter water."

   (c) Graph your results on the attached sheet, with "turbidity value" on the vertical (y) axis and amount or concentration of milk on the horizontal axis (x). Choose the scales for the axes to fit your data.

   (d) The graph should show that the ALTA turbidity value increases as the amount of milk increases, up to a point. If someone put some milk in your fish tank (starting with the same amount of water you did), how could you use this graph to tell how much milk was added?

   (e) At higher amounts of milk, your graph should become flat or even go back down to lower ALTA turbidity values. Why is this so? Look at the beam of light in the milky water, and see if it gets dimmer away from the lamp.

Extensions

1. *Food.* What kinds of drinks are turbid? [Orange juice, cider, some sodas, coffee, some beers.] How does their turbidity affect how you think about them? For example, what would you think of crystal clear orange juice? Would you drink turbid bottled water? How could a fruit juice or spring water company use turbidity measurements to help in manufacturing?

2. *Invention.* The design of the demonstration (fish tank or bottle in a darkened room) here would not work well in real world situations, such as trying to measure water turbidity in a stream or lake. Try designing a system (with a lamp and a sensor at right angles to the lamp) that could be used to measure water turbidity in the outside environment. The system should not be sensitive to water, should work in bright sunlight, and should be able to measure turbidity just at the water surface and to water depths of at least 20 feet.

3. *Colors and scattering.*

   (a) Shine a light through some milk. What color is the light after it passes through the milk? What happened to the light that didn't pass through the milk?

   (b) Repeat the experiment with the ALTA and fish tank using first a red filter (like cellophane) over the lamp and then using a green filter over the lamp. Which color is scattered more by the milk — red or green?

   (c) Take a survey of students (or others), asking why the sky is blue and why sunsets are red. Tabulate the answers. How many mentioned scattering of light in the air?

Lesson 7: Data Sheet 1.

Class: ________________________________ **Date:** ______________

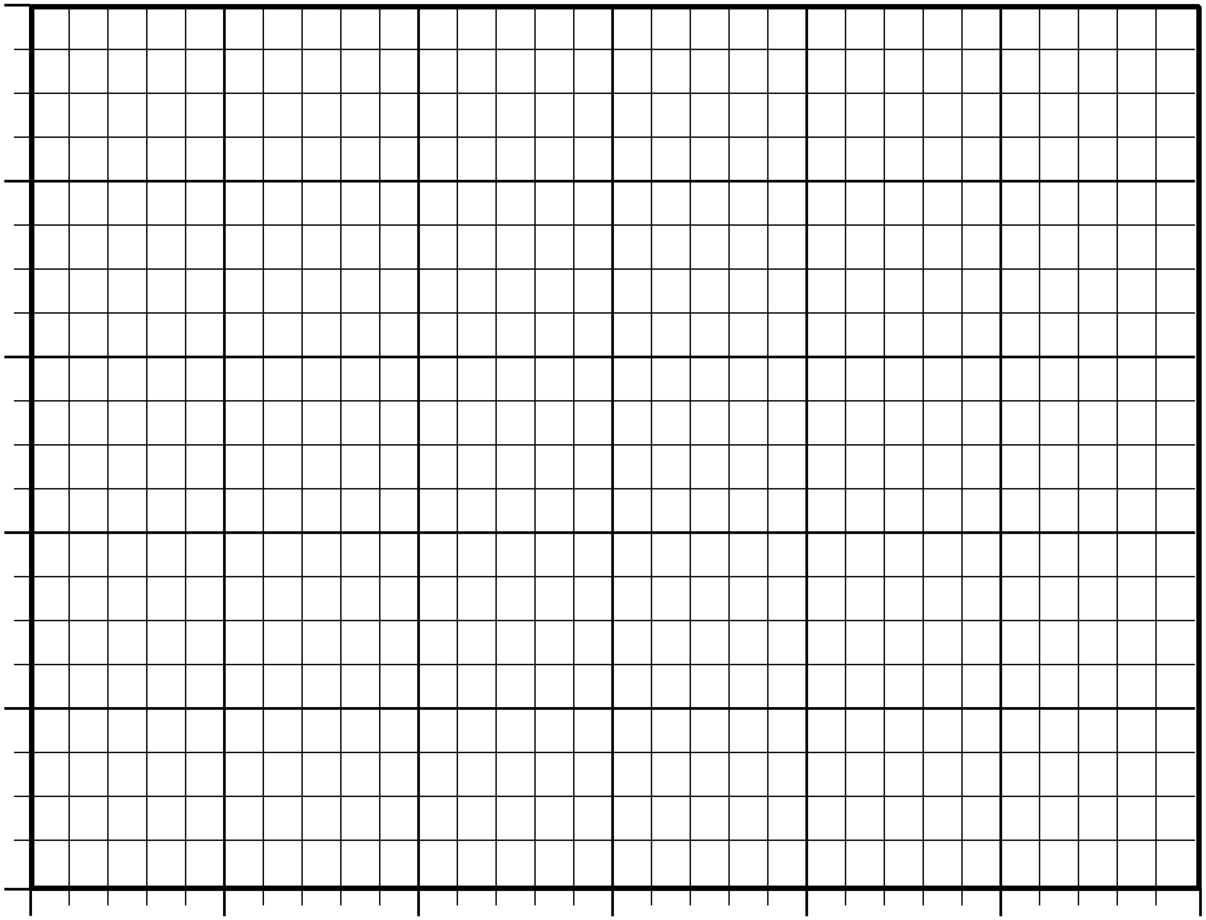
Scientist(s): ____

____

	Volume of Water in Tank:	
Background 1		
Background 2		
Background 3	(no milk)	(mV)

Step	Amount of Milk Added	Cumulative Amt. of Milk	Concentration Milk at This Step	ALTA Display Value at This Step	ALTA Display Value Minus Background 3 (ALTA Turbidity Value)

Lesson 7: Graph Template 1.



8 Clouds and Dust

Objectives

☞ Learn about particles in the air as a measure of cloud thickness and pollution.

☞ Collect, manipulate, and draw conclusions from physical data.

☞ Investigate the importance of experimental conditions on measured results.

About this lesson

This lesson is modeled on one of the cloud-detection experiments carried on the *Galileo Probe*. The probe was dropped into Jupiter's atmosphere to locate its clouds and to measure its density, temperature, and wind speed. The concept of this lesson, scattering of light by small particles, is like that of Lesson 7 (Water Turbidity), but the arrangement of the light source and the detector is more realistic for most applications (see Background and Extensions). The lesson is written as a classroom demonstration exercise because it requires a large experimental setup and careful control of room lighting. The influence of room lighting is a good lesson on the importance of experimental conditions: without careful controls, variations in room lighting can swamp the data you want to measure. The ALTA spectrometer is used only as a light meter; its own colored lamps are not used.

This lesson assumes that the students are acquainted with the ALTA spectrometer; if not, the instructor should integrate the classroom procedures of Lesson 3.

Materials

✔ ALTA spectrometers.

✔ Flashlight or lamp with a wide beam.

✔ Long (3 ft.) cardboard box, covered on the inside with black paper, with ports for ALTA photodetector, lamp, and smoke entry. (See Figs. 1 and 2 below.)

✔ Source of smoke: "canned" smoke, available from novelty stores and catalogs, works extremely well. Other sources are candles, long fireplace matches, etc.

✔ Clear tape or plastic to cover hole on the ALTA to protect detector from smoke particles.

✔ Data sheet and graph template (included).

Background

Measuring the abundance of particles in the air is useful in many aspects of science and everyday life. The particles might be droplets of water vapor (clouds and fog), dust, or soot and other hydrocarbons (smog or pollen). The environmental implications of air particles are obvious — they can affect our health, the quality of our lives, our safety while driving or flying, etc. This experiment doesn't use fog (as from dry ice) because it is difficult to quantify the thickness of the fog.

To detect clouds in Jupiter's atmosphere, the *Galileo Probe* shot a laser beam out and measured how much of its light was reflected back. The light detector was near the laser, which is how the lamp and ALTA are arranged in this lesson. The *Galileo Probe* was designed to measure the heights and abundances of particles of the topmost cloud layers, before the probe was crushed by the pressure of Jupiter's deep atmosphere. What we see of Jupiter is all clouds, but they are not all made of water droplets like Earth clouds — some are made of harsh chemicals like frozen ammonia (NH_3) and frozen ammonium hydrosulfide (NH_4SH). Before the Galileo mission, scientists had thought that the probe would encounter a layer of water ice clouds; it didn't, and the absence of water ice clouds is still a puzzle. For more information on the Galileo mission and its probe, consult the Jet Propulsion Laboratory's Internet site at http://www.jpl.nasa.gov:80/galileo/index.html.

Vocabulary

Particles, particulates, turbidity, scattering (as of light)

Procedure

PREPARATION

1. Cover the hole on the back of the ALTA with clear tape or plastic. This will keep smoke out of the ALTA.
2. Prepare a long box as shown in Fig. 1.

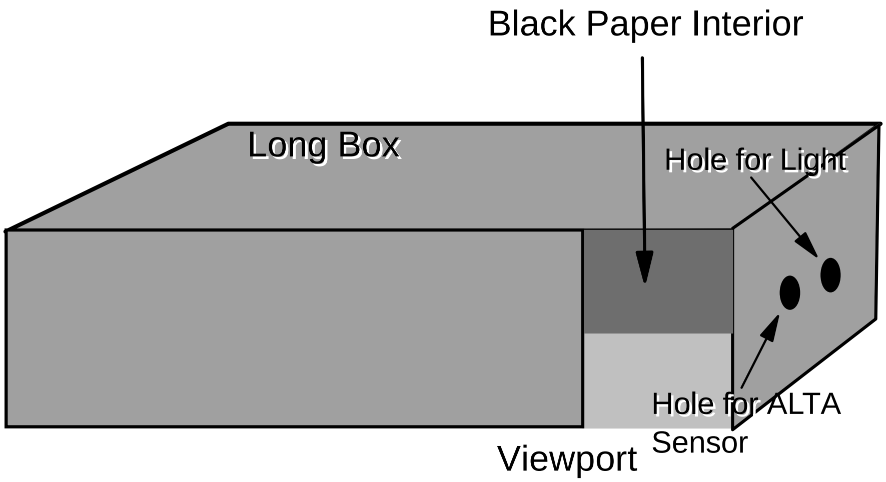


Fig. 1.

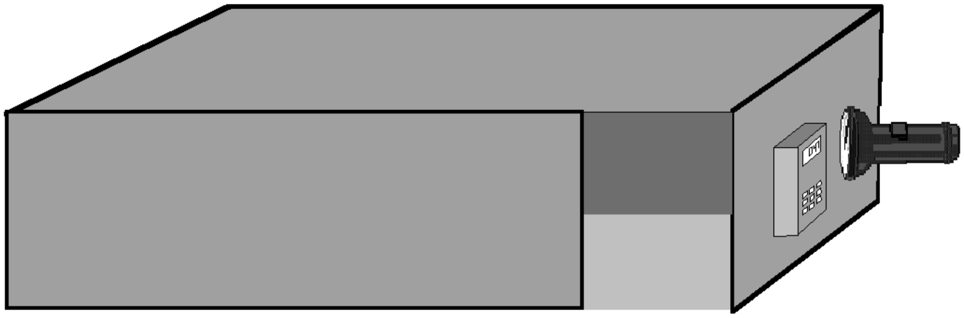


Fig. 2.

3. Set up the box, lamp, and spectrometer as shown in Fig. 2. The lamp should shine straight into the box along its long end. The ALTA should be placed on the same end of the box as the lamp, with the lamp as close to the ALTA photodetector as possible. The lamp and ALTA need to be held firmly in place against the box (use small boxes, books, and tape), because moving the light beam or the ALTA will affect the measurements. The cardboard box is to contain the smoke and to keep room light out as much as possible.
4. Read the classroom procedures.
5. To make “clouds” or “fog”:

   Choose an area of the room *away* from smoke detectors. It will probably be useful to open a window or have a fan handy to dissipate smoke safely.

   Using canned smoke, candles, long fireplace matches, or something similar, begin to put smoke into the box in gradual steps (i.e., by spraying small puffs of canned smoke, or by lighting a candle or match for a short period of time and blowing it out in the box). Repeat this step as measurements are made, trying to introduce about the same amount of smoke each time. If additions make little change in measured readings, increase the amount of individual smoke additions, recording the time in the “Smoke Additions (time)” column on Data Sheet 1.

CLASSROOM PROCEDURE 1: DATA COLLECTION

1. *Before the lesson.* Turn down the room lights with the experimental setup in place.
2. *Background Measurement 1.* With the room lights low, turn the ALTA on, but not the lamp. Do not use the ALTA colored buttons — this exercise does not use the ALTA’s own lamps. Record the display number on the data sheet. This number includes the dark voltage of the ALTA plus a response to the room light. Have students and objects move around the room a few times and record the ALTA display number each time. The ALTA number (the amount of light entering the spectrometer) should change as shadows fall on the ALTA and as light reflects into it. These changes demonstrate the importance of experimental design on the results of an experiment.

   Have a student stand in front of the box’s opening, and see if the ALTA display number changes — it likely will because the student will either block out light from the room or reflect light into the box. Record display numbers with students at various places around the room, to see how sensitive the experimental setup is to the positions of people (and things) in the room. Decide where people and things must stay for the following measurements, so their movement will not affect the results.

3. *Background Measurement 2.* With people and things in their standard places, turn on the lamp and record the ALTA display number on the data sheet. This is the response of the system (ALTA, lamp) to the empty box. If the background reading here is high (>300 or so), adjust the flashlight's beam direction and beam width to give a lower reading.
4. *Smoke.* With all people and things in their standard places, add a set amount of smoke to the tank. Record the ALTA display number. Repeat this procedure, adding smoke and recording the number. If additions of smoke make little change in the display number, puff in a little more canned smoke at a time or burn the candle or match a little longer per measurement. Continue adding smoke and recording data.

CLASSROOM PROCEDURE 2: DATA MANIPULATION

1. *Interferences.*

   What was the range of Background Measurements 1, from highest to lowest? How many smoke additions would it take to give the same number as the highest Background Measurement from part 1? From part 2? How important was it to have controlled shadows and reflected light from the room?

2. *Turbidity.*

   (a) On the data sheet, subtract the Background 2 measurement (lamp on, everyone and everything in standard places) from each of the ALTA measurements on smoky air. Write these differences in the proper column on the data sheet. These numbers provide a measure of how much light scattered from the smoke particles in the air into the ALTA, or the turbidity of the air.

   (b) On the data sheet, fill in the column "Cumulative Number of Smoke Additions." Abundance would usually be measured as "particles per cubic centimeter" or "particles per cubic meter," but we can't count the particles directly.

   (c) Graph your results on the attached sheet, with turbidity value (part 2a above) on the vertical (y) axis, and the cumulative number of smoke additions on the horizontal axis (x). Choose the scales for the axes to fit your data.

   (d) The graph should show that the ALTA turbidity value increases as the amount of smoke increases, up to a point. If someone put some smoky air in your box, how could this graph let you quantify how smoky the air was?

   (e) With very high amounts of smoke, your graph (part 2c) ought to become flat or even go back down to lower ALTA turbidity values. Why might this happen? For instance, how might black soot in the air be different from white powder?

Extensions

Inventions. Detecting fogs or dusts has many practical applications. Based on what you have learned from the design of this experiment, how would you make:

(1) A fog detector for cars that automatically turns on fog lights when the fog is thick enough. Make sure the sensor won't blind the driver.

(2) A sensor that activates a car's windshield wipers when they are covered by raindrops. Make sure the detector won't blind the driver.

(3) A sensor for airplanes that warns the pilot when visibility drops below the legal threshold for flying by VFR (visual flight regulations), requiring a switch to IFR (instrument flight regulations).

Lesson 8: Data Sheet 1.

Class: ________________________________ **Date:** ______________

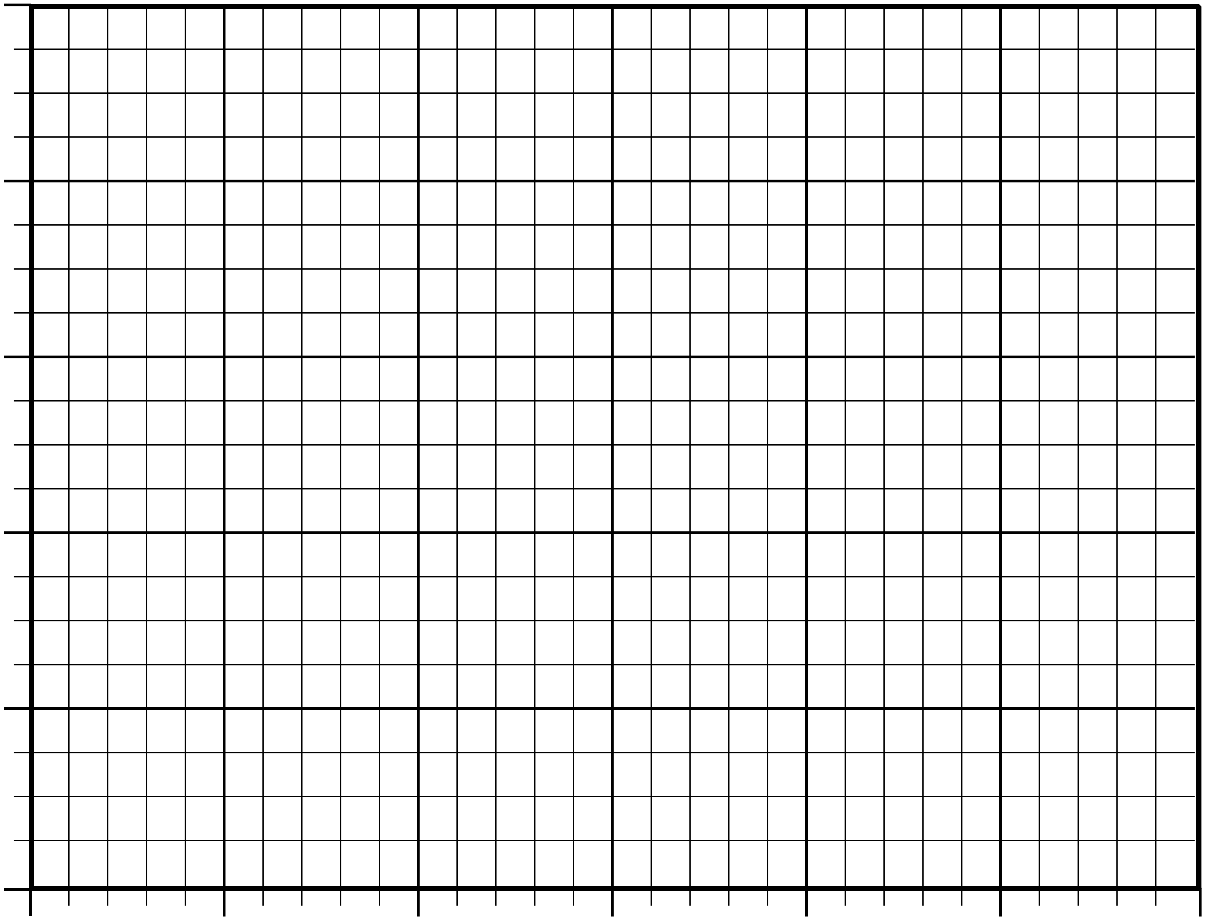
Scientist(s): ____

____

Background 1		
Background 2	(no smoke)	(mV)

Step	Smoke Additions (time)	Cumulative Number of Smoke Additions	ALTA Display Value at This Step	ALTA Display Value Minus Background 2 (ALTA Turbidity Value)

Lesson 8: Graph Template 1.



9 What Makes Mars Red?

Objectives

- ☞ Learn about planetary remote sensing.
- ☞ Learn about the concept of laboratory reference materials.
- ☞ Design an open-ended scientific investigation.

About this lesson

This exercise starts with reflectance spectra of Mars' surface materials, taken by the Mars Pathfinder lander in the summer of 1997. The task for the students is to find some reasonable materials (on Earth) that have reflectance spectra similar to the Mars surface. They will (with your coaching) design an experimental procedure to tell if a material's reflectance spectrum is "similar" to Mars', and will also select a group of materials to test for similarity to Mars. They may come up with one similar spectrum, many spectra, or none. All these outcomes are acceptable in the real world of science.

This exercise is much more open-ended than the usual classroom lab experiment, where a hypothesis is stated, investigations are made, and the hypothesis is either proved or disproved. But many scientific investigations are much broader, starting with an open-ended question of how something in the world works. The scientist must think of many possible answers and ways of testing them all. Here, students will start with the simple question, "What is reddish on Mars' surface?" and your students will test a series of hypotheses. Each hypothesis — each possible source of red color — may not seem like much toward knowing why Mars is reddish. For instance, it may not help much to know that Mars' reflectance spectrum is not the same as a Jonathan apple's.

This lesson must follow Lessons 1 (exploring the ALTA spectrometer) and 3 (taking a reflectance spectrum). This exercise leaves out detailed instructions on the spectrometer and taking a spectrum, but those procedures can be incorporated here.

Materials

- ✔ Color image of Mars, as from the Hubble Space Telescope, the Viking orbiter spacecraft, or the Mars Global Surveyor spacecraft.
- ✔ Color image of the Mars Pathfinder landing site, taken from the rover, showing rocks and sand and dust.
- ✔ Photocopies of the reflectance spectrum of Mars' surface, taken by the Mars Pathfinder lander (included).
- ✔ ALTA spectrometers.
- ✔ Lots of reddish and orange materials.
- ✔ Data sheet, worksheets, and graph template (included).

Background

The reflectance spectra of Mars that accompany this exercise were taken by the Mars Pathfinder IMP camera, on Mars, on the fourth day after landing (July 11, 1997). To get reflectance spectra of the martian surface, the IMP uses filters (like colored glasses) that are moved into the light path in the camera. Each of the 11 filters lets through only light of a particular wavelength; the wavelengths are 470 nm, 530 nm, 600 nm, 670 nm, 750 nm, 800 nm, 860 nm, 900 nm, 930 nm, 970 nm, and 1000 nm. To get a reflectance spectrum of a particular spot (like a rock), the IMP takes pictures of that spot through each of the filters.

Vocabulary

Mars Pathfinder, Mars Global Surveyor

Essential knowledge

1. Analyze and interpret information to construct reasonable explanations from direct and indirect evidence.
2. Communicate valid conclusions.
3. Collect data.
4. Construct graphs, tools, tables, maps, and charts using tools including computers to examine, organize, and evaluate data.

Procedure

PREPARATION

1. Photocopy the student instructions, worksheets, and the Mars Pathfinder reflectance spectrum of the martian dust.
2. Assemble some reddish/orangish objects suitable for reflectance spectra (solid, with relatively flat surfaces). Typical objects might include fruits, books, a brick, red rock, crayons, and lipstick.

CLASSROOM PROCEDURE

1. *Introduction.* Introduce the problem to the class by showing them a picture or slide of the entire planet Mars or of the Mars Pathfinder landing site. Hand out the Pathfinder reflectance spectrum of the martian dust as the target for their study. Ask, "What makes Mars reddish?"
2. *Experimental protocol.* Remind the students about color and reflectance spectra. Remind them how the ALTA spectrometer works and how to take a reflectance spectrum of a material. If needed, this is a time to demonstrate or have the students work through the in-class procedures of Lesson 3.
3. *Target materials.* What kinds of material might the reddish dust be like? Brainstorm a list of reddish/orangish materials, including ones that might make Mars red. Write all the suggestions down. You will likely get responses like apples, tomatoes, blood, rust, makeup, red rocks, paint, etc. Collect the ones in your classroom already, along with whatever red/orange colored materials you may have on hand. Assign students to bring in the items you do not already have.

4. *Experiments.* Assign each group a red material and have each obtain a reflectance spectrum of the material (definitely including standardization, and possibly including dark-current subtraction if the class is at that level of sophistication). Have each group tabulate and graph their results, and compare their reflectance spectrum with the Mars Pathfinder spectrum of the bright martian dust. Have each group present its results to the class (this should only take a minute or two) saying whether their material is possible or likely on Mars' surface. The group should comment on both the shape of the reflectance spectrum and the overall brightness (reflectance) of the spectrum. Post all the spectra on the board.
5. *Discussion.* Decide with the class which spectra they took are most like the spectra of Mars. Based on your selection of materials, what is your best inference about what makes Mars red? How could you improve your inferences, without going to Mars?

Extensions

1. *Literature/history.* Throughout history, the color of Mars has been the most important influence on how it was perceived. Explore how Mars' color led ancient Romans and Greeks to associate it with war. Percival Lowell, in the late 1800s, recognized that Mars' color was similar to the color of rocks and sand in many deserts on Earth. How did his interpretation of Mars' color influence his theory of Mars and the martians?

Lesson 9: Data Sheet 1.

Class: ______________________________ Date: ______________

Scientist(s): ____

____

		Dark Voltage (mV):			
		Voltage (mV)			
Color	Light Wavelength	Mars Sim. #1:	Standard: White Paper	Mars Sim. #2:	Mars Sim. #3:
Blue	470 nm				
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				

Lesson 9: Worksheet for Calculating Reflectance.

(Simple)

Class: ______________________________ **Date:** ______________

Scientist(s): ____

____

		Voltage (mV)		% Reflectance
Color	Light Wavelength	Mars Sim. # :	Standard: White Paper	(Sample Voltage ÷ Standard Voltage) × 100
Blue	470 nm			
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			

Lesson 9: Worksheet for Calculating Reflectance.

(Better, but more complicated)

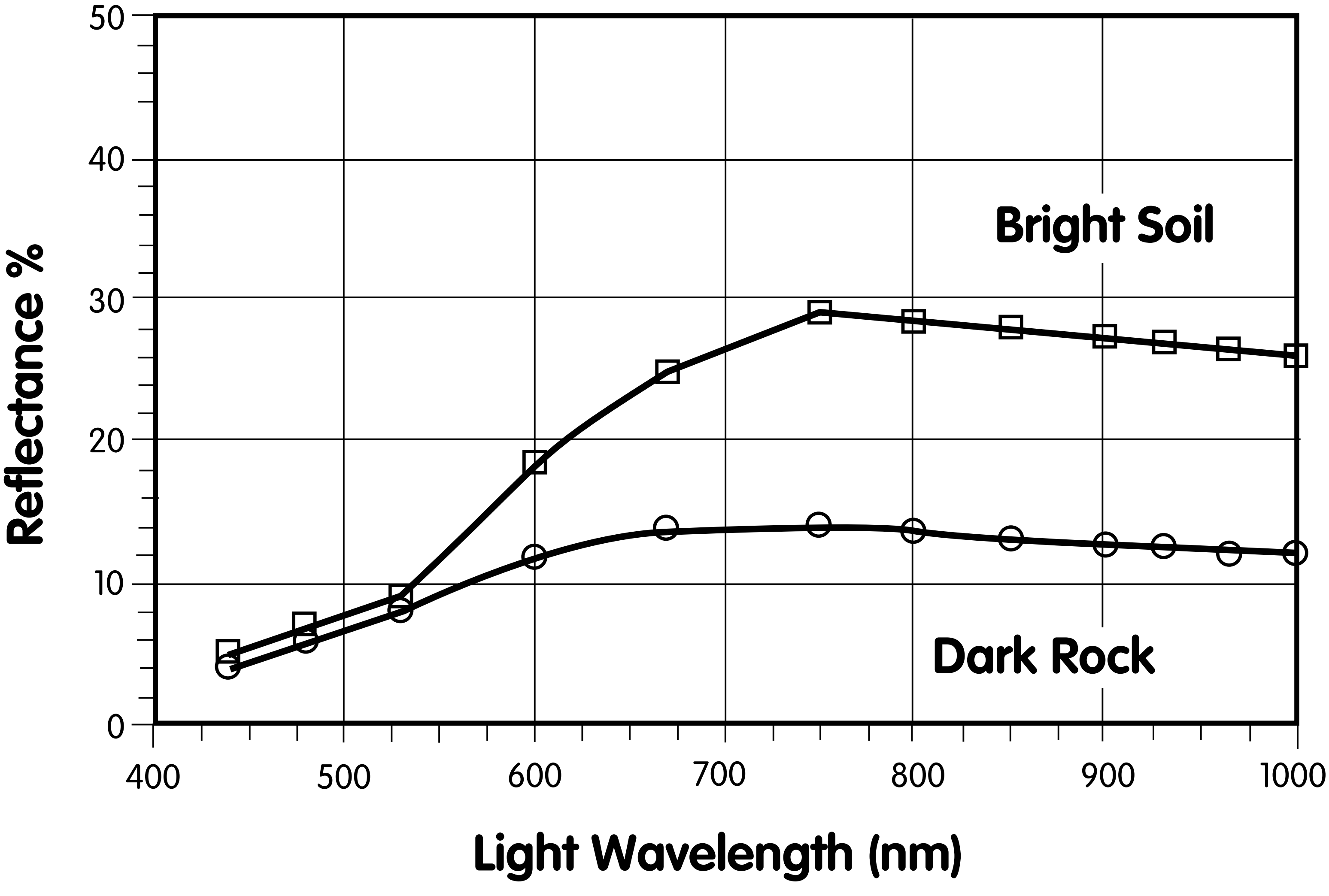
Class: ______________________________ **Date:** ______________

Scientist(s): ____

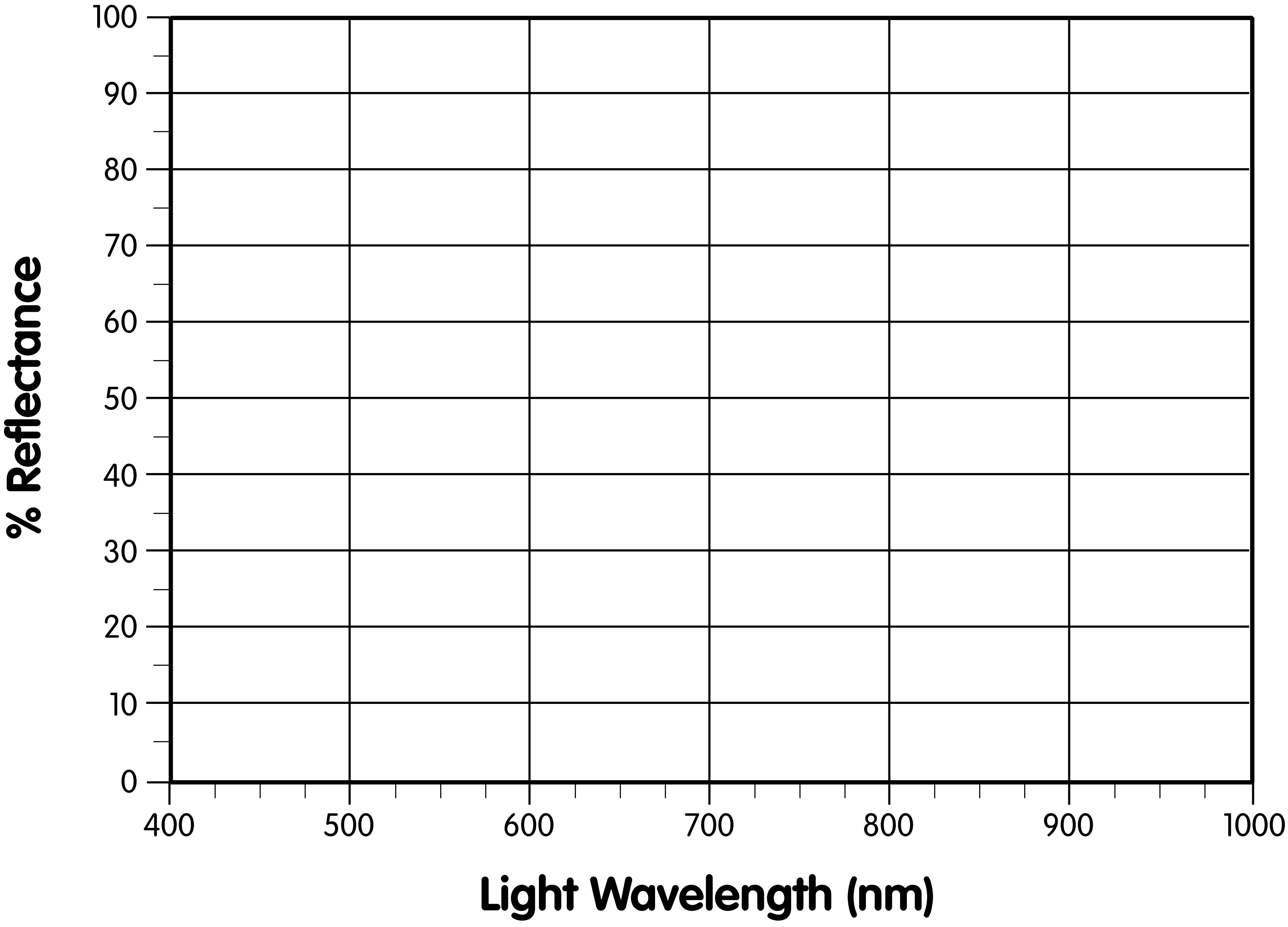
____

		Dark Voltage (mV):		
		Voltage (mV)		% Reflectance
Color	Light Wavelength	Mars Sim. # :	Standard: White Paper	$\left[\frac{\text{(Sample Voltage − Dark Voltage)}}{\text{(Standard Voltage − Dark Voltage)}}\right] \times 100$
Blue	470 nm			
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			

Lesson 9: Mars Pathfinder Reflectance Spectra



Lesson 9: Graph Template 1.



LESSON PHYSICS

10

The Inverse Square Law

Objectives

☞ Make and graph measurements of a physical quantity.

☞ Verify that the intensity of light decreases as the square of the distance from its source.

About this lesson

Here, the students will quantify and graph a common intuitive observation: that a lamp appears dimmer the farther you go from it. This observation leads to the *inverse square law* of light, radio waves, etc., which states that the intensity of light from a source (like a lamp) decreases as 1 over the square of the distance to the source. This law has important uses everywhere light is concerned: How bright should stop lights be to warn oncoming cars? How bright should bicycle lights be to alert motorists? How much power does a radio station need to broadcast all the way to Cleveland? Why is Mars colder than Earth? How strong does a spacecraft radio have to be to signal the Earth? And since spacecraft radios need power, how big do the spacecraft's solar panels need to be?

This lesson assumes that the students have used the ALTA spectrometer; if not, they should start with Lesson 3.

Materials

- ✔ ALTA spectrometers.
- ✔ Long table.
- ✔ Low-wattage incandescent lamp, for instance, a single lamp on a Christmas light string. If the lamp throws a distinct beam of light (like a flashlight), modified experimental procedures are required, as noted below with double asterisks (**).
- ✔ Low-wattage incandescent lamp.
- ✔ Tape measure or long measuring stick.
- ✔ Data sheet and graph template (included).
- ✔ Calculators (optional).

Background

The *inverse square law* is found in many parts of the natural world — the intensity of effects like light, gravity, and electrostatic force decrease with the square of the distance from the observer to the source:

$$I \propto \frac{1}{r^2}$$

In this lesson, the students will use the ALTA as a light meter and not as a source of light itself. The output voltage from the ALTA's light sensor changes with the intensity of light that hits it, and we use the voltage as a measure of the light intensity. The crucial thing is that the ALTA sensor has a *linear response* to light intensity — if the light intensity changes, the voltage changes by just the same proportion. There are two other sources of voltage that appear in the ALTA display: the rest of the light in the room (called background or ambient light) and the dark voltage (present without any light hitting the sensor). In an equation,

$$\text{Voltage} = (K \times \text{lamp intensity}) + (K \times \text{background light intensity}) + \text{Dark Voltage}$$

where K is a constant for the sensor. At each of a series of distances from the lamp, the students will measure and record two things: the voltage on the ALTA display with the lamp on and the voltage with the lamp off (which includes the dark voltage and the effect of background light). Subtracting these two measurements gives the voltage from the lamp intensity alone. And this voltage is a measurement of the intensity of light from the lamp.

Vocabulary

Intensity, square, power (as in watts of power), ambient

Procedure

PREPARATION

Before the class, figure out where the lamp should sit and from where the students will measure its brightness. The lamp should be fairly far away from the walls (so that little light reflects from the walls). The lamp could be on a long table. There should be enough room so that the ALTA spectrometer can be held and read with its opening toward the lamp.

**If you must use a flashlight, it should have a diffuse beam. Shine the flashlight at a wall — it should have a central bright area without rays, bright spots, or dark spots. If the central area is not uniformly bright, it will be nearly impossible to know if you are sending the same amount of light toward the ALTA.

CLASSROOM PROCEDURE

1. Describe the exercise to the students. They will be investigating how the brightness of a lamp seems to change as they move away or toward the lamp. Ask why this might be useful to know? [How far away they can see car headlights; how bright a flashlight should be; how bright streetlights need to be; how strong radio transmitters need to be.] They will use the ALTA spectrometer as a light meter to measure how the brightness changes as they move the spectrometer away from the light. Remind them that the numbers on the ALTA display change with the brightness of the light, and that the change is *linear.* This means that, for this exercise, they will NOT need to turn on the lamps in the ALTA.
2. Darken the room. It must be as dark as possible, but with enough illumination so that students can see the ALTA display and write on their data sheets.
3. Turn the lamp on. Have a student hold the ALTA with its opening pointed toward the lamp. Starting a foot or so away from the lamp, move the ALTA away from the lamp until the number on the ALTA display stops being “1—” and becomes a four-digit number like

"1965" (when the display is "1—", there is too much light for the ALTA to process accurately). Measure the distance from the lamp to the ALTA with the tape measure and record it on the data sheet. Record the four-digit display number in your data sheet in the same row as the distance. Cover or turn off the lamp and record that ALTA reading in the same row of the data sheet as "Background." [This is a measure all the other light in the room plus the dark voltage.]

**3a. If you have a flashlight or other lamp that emits a beam of light: Turn the flashlight on. Have a student hold the ALTA with its opening pointed toward the flashlight. Starting near the flashlight (two feet or so), hold a piece of paper in the flashlight's beam, and note where the beam is brightest. Place the ALTA so its photodiode (the center of the hole on the bottom) is at the brightest spot. If the ALTA display shows an overload ("1---"), move farther away from the light and find the brightest spot again. Repeat until the number on the ALTA display becomes a four-digit number like "1988." Measure the distance from the lamp to the ALTA with the tape measure and record it on the data sheet. Record the four-digit display in your data sheet in the same row as the distance. Without moving the ALTA, cover or turn off the lamp, and record that ALTA reading in the same row of the data sheet as "Background." (This is a measure of all the other light in the room plus the dark voltage.)

4. Repeat this procedure, moving the ALTA away from the lamp and always keeping its opening toward the light.
   (a) Move the ALTA farther away from the light.
   (b) Measure the distance from ALTA to lamp and record it on the data sheet.
   (c) Making certain that the ALTA's light sensor is pointed directly at the lamp, record the display number on the ALTA onto the data sheet.
   (d) Cover or turn off the lamp.
   (e) Record the background reading from the ALTA display onto the data sheet.
   (f) Uncover or turn on the lamp.

**4a. Flashlight only: Repeat this procedure, moving the ALTA away from the flashlight and always keeping its opening toward the light.
   (a) Move the ALTA farther away from the light.
   (b) Find the brightest spot in the flashlight's beam, and position the ALTA's light sensor there.
   (c) Measure the distance from the ALTA to the lamp, and record it on the data sheet.
   (d) Making certain that the ALTA's light sensor is pointed directly at the lamp, record the display number on the ALTA onto the data sheet.
   (e) Cover or turn off the lamp.
   (f) Record the background reading from the ALTA display onto the data sheet.
   (g) Uncover or turn on the lamp.

5. Finish at your discretion, or when the ALTA reading with the lamp on is less than twice the reading with the lamp off. (In the scientific lingo, when the signal is less than twice the noise.)

Data processing

1. *Calculation.* The light-intensity measurements with the lamp on also include the stray light (ambient light) in the room. You should find that the numbers decrease as the distance increases, but for a quantitative calculation, your students must remove the effect of the room light and the dark voltage. These calculations are outlined on the data sheet. For each distance, the student should subtract the ALTA voltage with the lamp off from the ALTA voltage with the lamp on, and write the results in the proper column on the data sheet. These voltage differences are the ALTA voltages that are due to the lamp alone. Are the “lamp off” measurements the same from near the lamp as they are far away? If not, why might the “lamp off” vary?

2. *Intensity vs. distance.* Your students will notice that the lamp intensities (ALTA voltages) decrease with increasing distance from the lamp — they have quantified their observation that the intensity of light from a lamp decreases as they move away from the lamp. But with the quantitative data, they can now do much more. Have them graph the distance and lamp brightness numbers on the attached graph template or a piece of graph paper. Make the graph with the distance to the lamp (the independent variable) on the horizontal axis, and the brightness number (the dependent variable) on the vertical axis. Their graphs will show that the lamp brightness does not make a straight line with distance — in scientific lingo, the intensity is not linear with distance.

3. *Distance dependence of light intensity.* Graph your data again, but instead of using “distance” on the horizontal axis (independent variable), use distance squared (distance^2) on the horizontal axis. In your data table, calculate the values of “distance^2” and write them in the column provided. Then, graph these values and the lamp brightness values from the table. Ideally, your graph will show that your data fall on nearly a straight line — that the amount of light from the lamp decreases as a linear function of the distance squared. This is the inverse square law.

Extensions

1. *Spacecraft communications.* Just like light, the intensity of radio waves decreases as the square of the distance from source to receiver. The *Mars Pathfinder* transmitted its signals to the Earth with a radio transmitter that used 12 watts of power. When Mars is farthest from Earth, how much weaker would the spacecraft transmissions be than when Mars is closest to Earth? How many watts of radio power would a spacecraft at Jupiter (like *Galileo*) have to use so its signal was as strong as *Pathfinder*’s when it was nearest Earth?

2. *Earth observation satellites.* The LANDSAT 4 and 5 satellites took images of the Earth from an altitude of 705 kilometers above the Earth’s surface. If a LANDSAT-like satellite were moved to geosynchronous orbit (35,800 kilometers above the Earth’s surface), it could look continuously down on a single part of Earth, and so get continuous imagery. But the satellite in geosynchronous orbit would have to be more sensitive to light reflected from Earth than the LANDSAT satellites. How much more sensitive would the new satellite have to be?

Lesson 10: Data and Worksheet.

Date: ____

Class: ____

Scientist(s): ____

____

	Display Voltage Numbers			
Distance	Measured: Lamp On	Measured: Lamp Off	Lamp Intensity (Lamp On-Off)	Distance Squared

Lesson 10: Graph Template 1.