Seeing the Moon

Using Light to Investigate the Moon

A Series of Inquiry Activities created for Chandrayaan-1's Moon Mineralogy Mapper Instrument

Through the hands-on inquiry based activities of *Seeing the Moon*, 5th to 8th grade students experiment with light and color, collect and analyze authentic data from rock samples using a reflectance spectrometer, map the rock types of the Moon, and develop theories of the Moon's history. The activities are divided into three primary "modules," with each module including open inquiry, demonstrations, hands-on activities, and a discussion to synthesize the students' understanding.

Content Objectives

Students will:

- Compare the characteristics of light of specific wavelengths to white light
- Demonstrate how spectra can be used to identify and map minerals and rocks
- Create a mineralogic map of the Moon based on data they collect
- Synthesize information about the Moon's topographic features and mineralogy to develop a hypothesis on the Moon's geologic history
- Describe why the spectra taken by the Moon Mineralogy Mapper / Chandrayaan-1 will obtain more information about the Moon than any observations to date

Inquiry Objectives

Students will:

- Develop descriptions, explanations, predictions, and models using evidence
- Use appropriate tools and techniques to gather, analyze, and interpret data
- Communicate scientific procedures and explanations
- Recognize and analyze alternative explanations and predictions

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Background

The Moon's Formation and Evolution

The current theory that best expains the scientific evidence is the "Giant Impactor Theory". In this model, early in the history of the solar system, the Earth collided with a small planet (approximately half the current size of Earth. The impacting planet was destroyed in the collision. Some rocky debris from that impactor, and less from the Earth, were hurled out into orbit around Earth. This material accreted — came together — to form the Moon. Some models suggest our Moon may have formed in as few as 10 years.

Early Stages: A Magma Ocean — As the rocky materials orbiting Earth accreted, the Moon grew larger and hotter. This heat formed an ocean of magma.

The evidence for a magma ocean comes from the layering of the Moon's interior. The uppermost part of the Moon's crust is mainly the rock anorthosite, which is primarily made of a single mineral, plagioclase feldspar. This rock forms the "lunar highlands," the bright white, heavily cratered regions we see on the Moon. Deeper parts of the Moon's crust and mantle include larger amounts of other minerals, such as pyroxene and olivine. As the magma ocean cooled and crystallized over a period of 50 to 100 million years, light-weight minerals such as plagioclase floated to the top, while denser minerals (such as pyroxene and olivine) sank. The oldest rocks collected by the Apollo astronauts are 4.5 billion years old, which is thought to indicate when the Moon solidified.

Big Impacts, Big Basins — Early in our solar system's history, the Moon and all other planetary bodies, were bombarded by large asteroids. These left scars; giant basins such as Imbrium, Crisum, and Serenitatis, hundreds of kilometers across, occur where they struck the Moon. The upturned rims of these basins form mountain chains on the lunar landscape. The impacts broke apart the rocks at the surface of the Moon and fused them into impact breccias, which are rocks made of angular, broken fragments, finer matrix, and melted rock. Impact breccias collected by the Apollo astronauts provide scientists with ages of formation of the basins, ranging from 3.8 to 4.0 billion years ago. By 3.8 billion years ago, this period of intense bombardment came to a close; since then, asteroid impacts have been much smaller and less frequent.

Basin Filling — Billions of years ago, the Moon was still hot, warmed by radioactive decay of unstable isotopes of elements, impacts, and left-over energy from the giant impact that formed it. Pockets of hot mantle material slowly rose to the surface, melting and forming lava as they moved up to lower pressures. This lava erupted through fissures, cracks in the lunar surface, many of which were created by earlier impacts. The lava flooded across the lowest regions on the lunar surface: the giant impact basins. It crystallized quickly, forming a dark, fine-grained volcanic rock, basalt. The large, smooth, dark regions we see on the Moon are the basaltic "lunar maria." They are smooth because they are less cratered than the lunar highlands. The smaller number of craters suggests that these regions have not been impacted as frequently and therefore are younger. Maria basalts have been dated to be between 3.1 and 3.8 billion years old. Gradually, as the Moon cooled, volcanism ceased.

All of these lavas are basalts, but there is a wide range in their minerals and compositions, because the lavas formed in different places (and from different mantle rocks) inside the Moon.

Recent History — For the last billion years, our Moon has been geologically inactive. It has no atmosphere, flowing water, or life to erode or disturb its surface features. Only impacting meteoroids, a few spacecraft, and the footsteps of 12 humans have reshaped its surface. The data returned by orbiting spacecraft and by the Apollo program reveal much about the formation and evolution of our Moon and, in turn, of our own Earth. Resurfacing processes active on Earth have obscured its early history of formation, differentiation, and asteroid bombardment. New spacecraft missions will help scientists piece together the details of history and evolution of the Moon — and Earth — and will lead to an understanding of lunar processes and distribution of resources in preparation for prolonged human habitation of the Moon.

Human Exploration of the Moon

Between 1969 and 1972 six manned Apollo missions brought back 382 kilograms (842 pounds) of lunar rocks, core samples, pebbles, sand and dust from the lunar surface. Each trip to the Moon took about 3 days to reach the Moon and another 3 days to return. These samples have been analyzed by scientists to better understand the Moon's composition, formation, structure, and geologic history. The Apollo explorations covered only 95 kilometers (60 miles) of the Moon's surface – a small percentage!

A New Age of Discovery

The United States has set new goals for the Moon: NASA plans to return to the Moon by 2020, as the launching point for missions beyond. To achieve this, NASA will send human mission back to the Moon as early as 2015, with the goal of living and working there for increasingly extended periods of time. In order to achieve these goals, NASA is planning robotic missions to study the Moon for possible landing sites, examining the Moon's natural resources, and preparing technology suitable for future human landings.

As we study the Moon today, we are preparing for tomorrow's exploration. Your students may be among the next generation of astronauts and space explorers; we welcome them to join in these activities as today's scientists examining the Moon.

The Chandrayaan Mission and the Moon Mineralogy Mapper Instrument

The Indian Space Research Organisation will launch its first mission to the Moon in 2008, with an instrument provided by NASA to map the mineral composition of the lunar surface.

The Moon Mineralogy Mapper (M^3) is a state-of-the-art imaging spectrometer which will examine lunar mineralogy at high spatial and spectral resolution. It will map the entire lunar surface from an altitude of 100 kilometers (62 miles) at 140 meter spatial sampling and 40 nanometer spectral sampling, with selected targets mapped at 70 meter spatial and 10 nanometer spectral resolution. M3 will be launched aboard India's Chandrayaan-1 spacecraft in March, 2008. The mapping mission will last two years.

This information will be important both for science and human exploration. A detailed characterization of lunar surface mineralogy can dramatically improve our understanding of the Moon's origin and geologic evolution, as well as the early development of the Earth. A detailed map of lunar resources will also be needed by future astronauts who may live and work on the Moon.

M^3 will be one of 11 instruments onboard the spacecraft, of which six will be Indian, two will be American, and three will be from other countries.

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M3 Activities Correlated with National Science Education Standards

Description of Standard	Activity 1A	Activity 1B	Activity 1C	Activity 1D	Activity 2A	Activity 2B	Activity 3A	Activity 3B
Content Standard A: Science as Inquiry								
Abilities to do Inquiry: Develop descriptions, explanations, predictions, and models using evidence					■			■
Abilities to do Inquiry: Use appropriate tools and techniques to gather, analyze, and interpret data.	■	■	■	■		■		
Abilities to do Inquiry: Communicate scientific procedures and explanations	■	■				■		■
Abilities to do Inquiry: Recognize and analyze alternative explanations and predictions	■	■				■		■
Mathematics is important in all aspects of scientific inquiry.			■	■		■		
Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.		■	■	■	■	■		■
Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.	■					■		■
Asking questions and querying other scientists' explanations is part of scientific inquiry. Scientists evaluate explanations by examining and comparing evidence, identifying faulty reasoning, and suggesting alternative explanations for observations.	■	■				■		■
Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data..				■				■

Content Standard B: Physical Science	Activity 1A	Activity 1B	Activity 1C	Activity 1D	Activity 2A	Activity 2B	Activity 3A	Activity 3B
Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection). To see an object, light from that object--emitted by or scattered from it--must enter the eye.	■	■	■	■	■	■		
The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.		■	■		■			

Content Standard D: Earth and Space Science	Activity 1A	Activity 1B	Activity 1C	Activity 1D	Activity 2A	Activity 2B	Activity 3A	Activity 3B
Land forms are the result of a combination of constructive and destructive forces..								■

The earth is the third planet from the sun in a system that includes the moon…								

CONTENT STANDARD E: Science & Technology

Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena.

Assessing Current Understanding

What do your students know about white light and the frequencies of light? What do they know about the Moon and current robotic space missions?

You may wish to spend some time during the activities or before beginning the activities discovering your students' current knowledge and understanding of the concepts to be presented so that you can ensure you will meet your learning objectives.

There are many common misconceptions about light and the electromagnetic spectrum documented for middle school to college students. These include:

- An object is seen whenever light shines on it, with no recognition that light must move from the object to the observer's eye.
- An object can be seen in the dark, with absolutely no light, as long as the observer's eyes have had time to adapt.
- We see by looking (visual ray idea) not by light being reflected to our eyes.
- Light is reflected away from shiny surfaces, but light is not reflected from other surfaces.
- Different forms of light include "natural", "electric", "ultraviolet", and "radioactive".
- When light passes through a prism or a filter, color is added to the light.
- Color is a property of an object, not affected by the illuminating light.

There are also misconceptions regarding NASA's exploration of the Solar System. Some students may believe that humans have never been to the Moon, while others may believe that astronauts have visited many of the planets in the Solar System. Students may not be aware of past or ongoing scientific robotic missions to our Moon and other planets.

Assessment Activities 1 and 2 will help you determine your students' current understanding of light and of our exploration of the Solar System.

Assessment Activity 1: The Little Bit of Light

In this 10 minute activity, students complete a story about light. The teacher will then examine their stories for key concepts and (mis)preconceptions regarding how we see and the role of light in seeing.

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Anticipated class time: 10 minutes

Objectives:

- The teacher will be able to use the results of this activity to better understand his or her student's preconceptions of sight.

Key Concepts:

- Light travels or moves until it is reflected or absorbed by an object.
- Light can be reflected, or "bounce" off of any object (not just mirrors).
- In order for a person to see something, light must be reflected off of that object and into his or her eye(s).

Materials

For each student:

- One copies of the Story of the Little Bit of Light
- Pen or pencil
- Colored pencils

The Activity:

1. Hand out copies of the *Story of the Little Bit of Light* to your students. Let them know that this science writing activity is for you and that their work will not receive a grade—this is not a test.

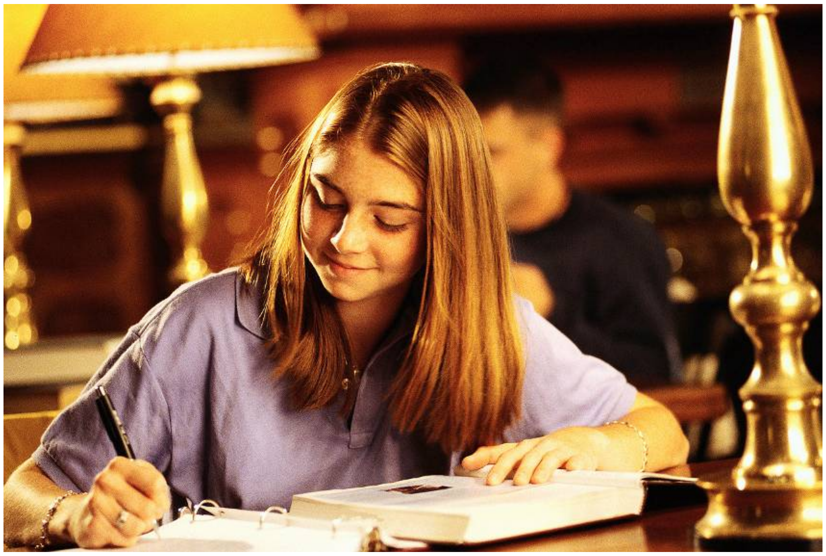
2. Let the students know they have 10 minutes to write the rest of the story. Their assignment is to write what happens to the light –*what does it do?, where does it go?, so that the student in the photo can see the book*. Remind the students that this is a science writing exercise; you would like a scientific story about the light, not a fictional story.

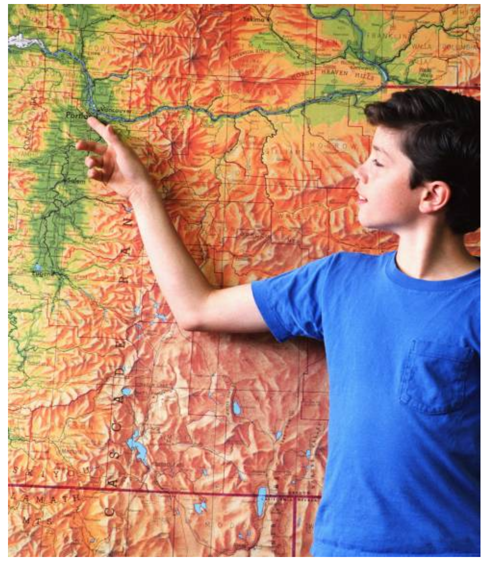
3. At the end of 10 minutes, collect the students' work. Outside of class, examine the stories for indications that the students understand that light keeps moving (instead of stopping), that the light reflects or hits objects, and that it does travel to the child's eyes in order for him or her to see.

4. Keep your students' preconceptions in mind while conducting the activities in these modules and address them throughout the activities. If there is substantial confusion as to how we see, consider discussion and activities about sight and seeing before conducting the activities in the modules.

5. Re-apply the assessment after the students complete further exploration of light, the electromagnetic spectrum, and how we see, to assess if there has been an increase in their understanding of these concepts.

The Story of a Bit of Light





Finish the science story, using one of the two pictures above,
ending with a student seeing the object(s):

I am a little bit of light. I was formed inside a light bulb inside a lamp in a dark room with no windows. I moved through the glass of the bulb and then I

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Assessment Activity 2:
The Electromagnetic Spectrum

In this 15 minute activity, students write a description or draw a spectrum that includes the different types of light or radiation, and then compare two of the types of light, to allow the teacher to assess their understanding of the electromagnetic spectrum.

Objectives:

- The teacher will be able to use the results of this activity to better understand his or her student's preconceptions or misconceptions about the spectrum.

Key Concepts:

- White light can be broken down into different colors.
- There are different types of visible light, ranging from blue to red, and types of light that we cannot see (radio waves, infrared, ultraviolet, x-rays, and gamma rays).
- Different types of light have different frequencies, which correspond to different amounts of energy and different wavelengths.

Materials

For each student:

- a sheets of paper
- Pens or pencils
- Colored markers, pencils or crayons

The Activity:

1. Hand out blank sheets of paper and (if desired) markers or crayons to your students. Let them know that this activity is for you and that their work will not receive a grade—this is not a test.

2. Let the students know they have 10 minutes. Their assignment has two tasks:
   a) Write about or to draw and label the electromagnetic spectrum.
   b) Write down a comparison of two of the different types of light that make up the spectrum.

3. Collect the students' work. Outside of class, examine the stories for indications that a spectrum is made of light, and that it has been divided into different colors. Look for other concepts in both tasks relevant to your students' experiences and your grade level's standards—such as frequency, wavelength, energy, and types of light that are not visible.

4. Keep your students' preconceptions in mind while conducting the activities in these modules. If you have questions whether students' understood something, you will want to bring it up for discussion.

5. You can re-apply the assessment at the close of the ALTA activities to see if there has been an increase in understanding.

Module 1

In this module, students will be introduced to the visible and infrared portions of the electromagnetic spectrum, take a spectral measurement using the ALTA reflectance spectrometer, and receive an introduction to the Moon Mineralogy Mapper / Chandrayaan-1 Mission.

Activity A. Experimenting with Color Filters (30 minutes)
Students begin their exploration of the properties of light. They observe different colors of construction paper using colored filters as eyeshades, and discuss their findings. Based on their observations, students make and test predictions of the appearance of other colors through the colored filters.

Activity B. Making Observations of Spectra (30-50 minutes)
This activity introduces the concept of a spectrum, including both visible light and wavelengths that are not visible to human eyes. Students observe a light spectrum, created using a diffraction grating and an overhead projector. Students experiment with observations of the spectrum, using their color eyeshades and construction paper, and a solar-cell and sound amplifier to detect near-infrared light through sonification.

Activity C. Introduction to the ALTA Spectrometers (60 minutes)
Using the ALTA reflectance spectrometer, students take readings of different colored objects at different wavelengths, and graph a reflectance spectrum for those objects. Students compare their reflectance spectra graphs and observe that different objects have different spectra.

Activity D. Spectrometers in Action (25 minute)
Students collect reflectance spectra and discover that objects that appear similar can have different spectra. Students discuss the advantages of a high-resolution spectrum to identify objects, and learn about the Moon Mineralogy Mapper / Chandrayaan-1 mission.

Activity A: Experimenting with Color Filters

Overview

In this 30 minute exploration, students begin their exploration of the properties of light. They observe different colors of construction paper using colored filters as eyeshades, and discuss their findings. Based on their observations, students make and test predictions of the appearance of other colors through the colored filters.

Learning Objectives:

The student will:

- interpret the relationship between an object's appearance or color and the light reflected off of that object.
- compare reflection and absorption of light by an object.
- describe the role of predictions and testing in the process of science.

Key Concepts:

- An object's appearance or color depends on the light reflected off the object that reaches our eyes.
- Objects absorb some colors of light and reflect other colors of light.
- Scientific investigation includes making observations and making and testing predictions.

Materials:

For each student:

- Two different 2" x 6" strips of color gels sheets (color filters) and
- 4 pipe cleaners
  Or
- One color paddle with multiple color filters

For each group of 4 to 5 students:

- One-hole punch
- Scissors
- Sheets of colored construction paper: red, dark blue, yellow, green, orange, and two additional colors
- Student Data Sheet: *Experimenting with Color Filters* ***(Link to URL)***

Gels can be purchased from a variety of locations, including http://stagelightingstore.com/, http://www.stagespot.com, and http://www.premier-lighting.com
Gels come in 20x24" sheets; each will produce 40 sets of eyeshades. Recommended Roscolux colors include: red #27, blue #83, green # 91, orange #23, and blue-green #95.

Prepared paddles of colored gels can be purchased at http://store.rainbowsymphonystore.com

Preparation:

Cut the color filters into 5 by 15 centimeter (2 by 6 inch) strips, with two different colors for each of your students. Each sheet will make 40 strips.

The Activity:

1. Making the Color Eyeshades: Give each student two different color filter strips and four pipe cleaners. Ask your students to punch one hole in both ends of each strip, about 1 centimeter (1/2 inch) from the edge. Ask students to pull a pipe cleaner halfway through each hole. The students should bend the pipe cleaners in half and twist the two halves together. By curling the ends of the pipe cleaners behind their ears, your students now have two color eyeshades to wear over their eyes or glasses.

   Alternative: hand out one color paddles per student.

To maintain standards of hygiene, the students should not share eyeshades.

For their safety, students wearing dark colored gels should remain seated.

Remind the students never to look directly at the Sun with their eyeshades; even dark eyeshades will not protect their eyes.

2. Invite the students to observe clothes and objects in the room, and to share what they see, Students may comment that objects appear darker or brighter, or appear to be a different color. As they discuss their observations, ask them to look for patterns. Your students may notice that light colored object still appear bright through most filters, but darker colored objects are only bright through some filters. For instance, dark red objects will be much brighter through a red filter than through a blue filter.

Some students may have partial or complete color-blindness. Depending on the severity of the condition, some of the color-related activities may be difficult for them.

Be prepared for the possibility that your students may be unaware that they are color-blind. They may be disturbed by this discovery. Alternately, if the student is comfortable with discussing their vision, it may also be a useful point of discussion and observation.

To make the activity accessible for the students who are color blind, you might use textured or patterned surfaces in addition to the colors.

3. Organize the students into groups of 4 to 5, making sure that each group has all of the different colored eyeshades. Give each group a sheet of red, dark blue, yellow, orange, and green construction paper.

4. Ask your students to observe the different sheets of construction paper through their eyeshades, describing what they look like—does the paper look brighter, darker, or a different color? Students should record their observations on their group's *Student Data Sheet*. While comments may vary, in general the blue eyeshades will make red construction paper look dark grey and will make the blue construction paper appear brighter than the other papers. The red eyeshades will do the opposite.

5. Ask the students to remove their color eyeshades and discuss their recorded observations and look for patterns.

6. Pass the two other colors of construction paper out to the groups. Each group should write a prediction of what they will observe if they look at the new colors through their eyeshades.

7. Encourage the students to test their predictions. Did their predictions match their observations? Ask each group to devise an explanation for their observations.

8. As a class, invite the students to share their groups' predictions, outcomes, and any explanations they have devised.

9. Invite your students to discuss their findings.

   What do the students think of the various explanations from the groups? Are there any that they think may be mistaken—why? Are there ways to test any of them? [Let the students critically examine each group's hypotheses. You may want to point out that important aspects of "doing science" include arriving at results, sharing those results, evaluating each others work, and proposing alternative ideas.]

   What do the students think the point of the activity was? [Answers may vary greatly, but could include observing colors, testing how color filters affect objects' appearances, and studying how filters absorb colors of light.]

   Which aspects of science did your students do today? [Answers could include making observations, making predictions, testing predictions, and forming hypotheses.]

   We need light in order to see. What does light do to let us see something? [In order for us to see something, light is reflected off that object's surface and into our eyes.]

How does light allow us to see an object's color? [The object absorbs some wavelengths or colors of light, and reflects other wavelengths or colors of light. The wavelengths that are reflected give the object its "color."]

What did the color eyeshades do to the light before it reached our eyes? [The eyeshades absorbed some of the colors of light, and allowed other colors to pass through. The eyeshades did not add color.]

If red eyeshades allowed red and orange light through, what would dark blue paper look like through red eyeshades? Why do red eyeshades make yellow and white paper look red? [Almost all of the light reflected off of the blue paper was absorbed by the red filter, making the blue paper looked black. Yellow and white papers reflect many colors; red filters absorb most of these colors but allow the red light to pass through, making those sheets of paper appear red.]

Background

Seeing Color

In order to see an object that is not emitting light, there must be some light reflecting off of that object, and some of that light must be reflected from the object and into our eyes. Most materials absorb specific wavelengths, or colors, of light and reflect the rest.

When we see white, all of the colors or wavelengths have been reflected off the object. Materials that absorb almost all of the light appear black. We can still see black objects, because they still reflect some light.

Team Members

________________________________ ________________________________

________________________________ ________________________________

Observation Sheet: Experimenting with Colored Filters

Descriptions can include: bright, very bright, dark, very dark, or a color:

_________ *colored paper looks* ______________________ *through a* __________ *filter.*

_________ *colored paper looks* ______________________ *through a* __________ *filter.*

_________ *colored paper looks* ______________________ *through a* __________ *filter.*

_________ *colored paper looks* ______________________ *through a* __________ *filter.*

_________ *colored paper looks* ______________________ *through a* __________ *filter.*

_________ *colored paper looks* ______________________ *through a* __________ *filter.*

_________ *colored paper looks* ______________________ *through a* __________ *filter.*

_________ *colored paper looks* ______________________ *through a* __________ *filter.*

Talk with your team: Why do the different colored papers look different through colored filters? Are there any patterns to what you see?

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Can you make some predictions based on your observations so far? Try to predict what a different colored sheet of construction paper that you haven't used yet would look like through the different filters.

_________ *(colored) paper will look* ________________________ *through a blue filter.*

_________ *(colored) paper will look* ________________________ *through a red filter.*

Now test your predictions:

_________ *(colored) paper appeared* ________________________ *through a blue filter.*

_________ *(colored) paper appeared* ________________________ *through a red filter.*

Discuss with your team: did your observations match your predictions? Do you have a theory to explain your observations?

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Activity B: Making Observations of Spectra

Overview

This 30 to 50 minute activity introduces the concept of a spectrum, including both visible light and wavelengths that are not visible to human eyes. Students observe a light spectrum, created using a diffraction grating and an overhead projector. Students experiment with observations of the spectrum, using their color eyeshades and construction paper, and a solar-cell and sound amplifier to detect near-infrared light through sonification.

Learning Objectives:

The student will:

- define what is meant by a "spectrum."
- describe different wavelengths of visible light as different colors.
- describe some wavelengths of light that are not visible to human eyes.

Key Concepts:

- White light is made of many different colors, or wavelengths of light.
- When white light is divided into its different wavelengths, we call it a spectrum.
- Each color or frequency of light has a corresponding wavelength.
- There are frequencies or wavelengths of light that are not visible to the human eye.
- Scientific investigation includes making observations, making and testing predictions, and sharing and skeptically examining explanations.

Materials:

For each student:

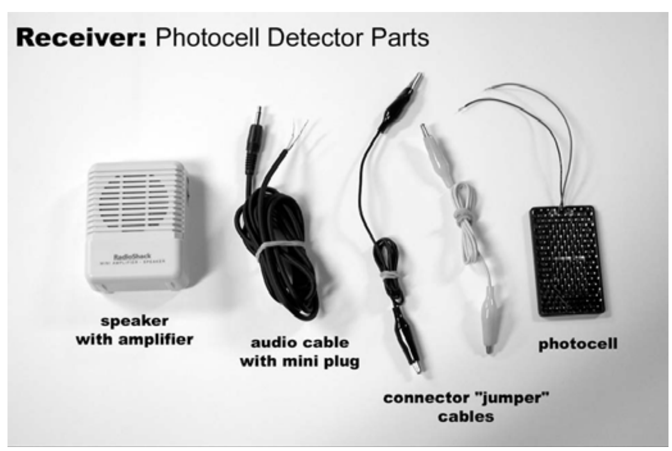
- Color eyeshades or color paddles from *Activity A*

For the class:

- A dozen sheets of various-colored construction paper
- 1 Diffraction grating
- 1 Overhead projector
- 1 roll of masking tape
- Scissors

Receiver Circuit

- Solar cell*
- Amplifier/Speaker
- Audio cable with 1/8 inch mini-plug on one end
- 2 jumper cables with alligator clips on both ends



- 9 volt battery for amplifier/speaker
- Small phillip's head screwdriver to open amplifier/speaker
- Small handheld fan

Infrared Camera (Optional)

- Infrared camera
- BNC to VGA adaptor (male to male)
- DC power adaptor
- Video projector
- Remote control for tv, dvd, or similar electronic device

Diffraction Grating material comes in sheets from suppliers such as Learning Technologies (PS-08A or PS-08B) and from Sargent Welch (WL3820).

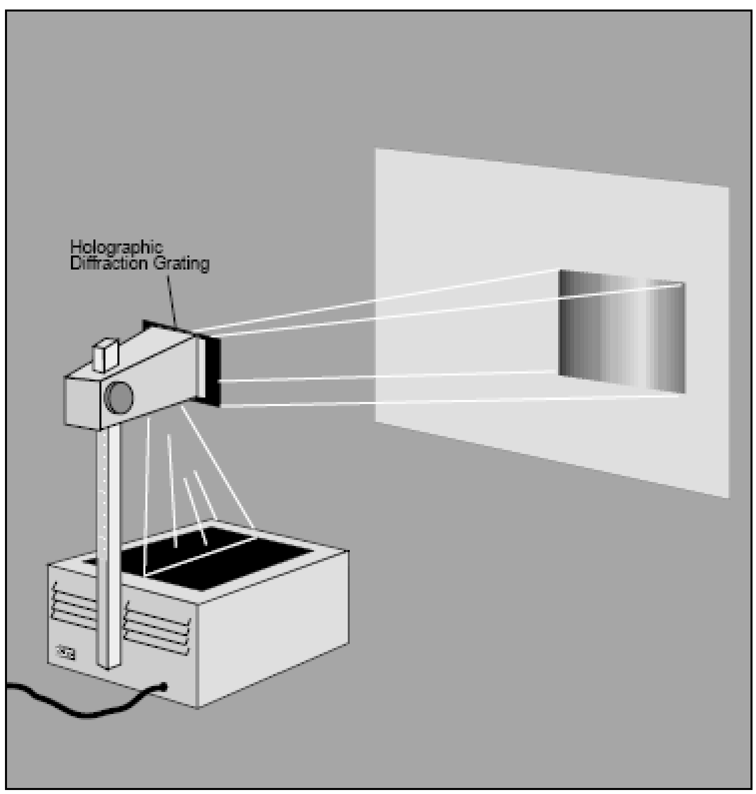
For the audio detector, the mini Audio Amplifier is available at suppliers such as Radio Shack (277-1008), as are alligator clip cables; the photocell is available from suppliers such as Solar World (#3-300).

For the infrared camera, a mini lipstick camera is available from suppliers such as LDP LLC (XNiteCamBtBW) and the rest of the materials are available at many A/V and electronics stores.

Preparation:

1. Set up the overhead projector so that it can project onto a flat white surface (screen or wall) in a dark part of the classroom.

2. Cut a small slit ½ centimeter (¼ inch) wide, but at least 10 centimeters (4 inches) long in the middle of the construction paper. Place the construction paper on the projector's glass so the only light emerging from the projector passes through the slit.



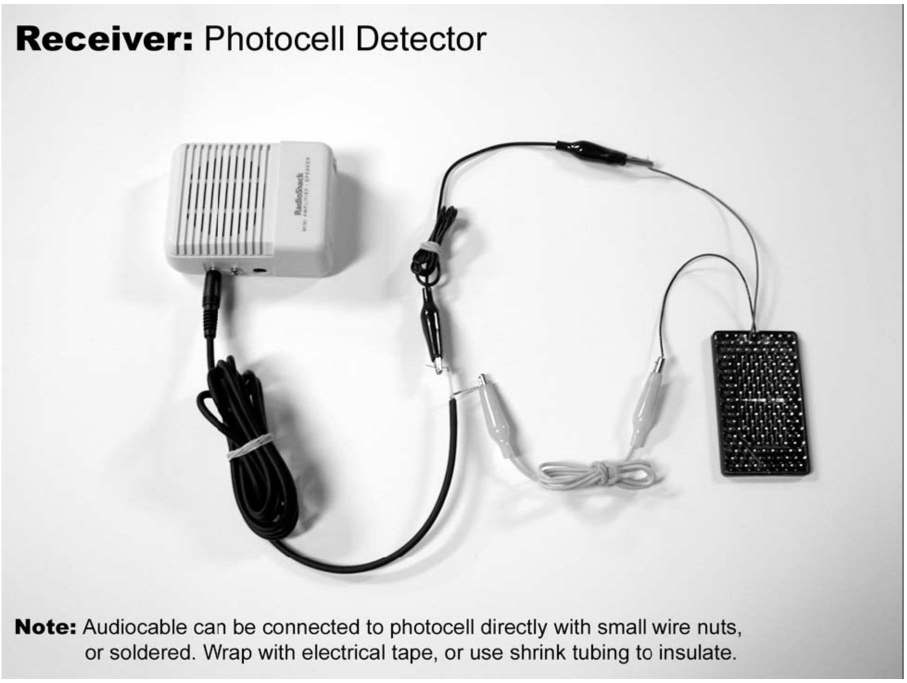
3. Turn on the overhead projector—you should see a white line of light projected onto the screen or wall.

4. Place a sheet of diffraction grating over the top portion of the overhead projector projecting the light. Adjust the sheet and projector until you

can clearly see one or two spectra clearly on the wall. Tape the diffraction grating in place.

5. If you plan to use the infrared camera (optional), turn it on by plugging it into a DC power adaptor, and plug the power adaptor into the wall. Attach the BNC-VGA adaptor to the camera's video cable, then plug it into the input for video on your video projector. Turn on the video projector (facing a different direction from the projected spectrum) and point the infrared camera at the spectrum. Observe the video to make sure it works. NOTE: you will not see the infrared part of the spectrum until you cover the camera with colored filters.

6. Build the audio photocell detector. Install a 9V battery in the audio amplifier. Plug the 1/8 inch mini plug into the "input" of the audio amplifier. Clip a jumper cable to one of the leads on the photocell, and clip the other end of the jumper cable to one of the leads of the audio cable. Use the second jumper cable to connect the other lead from the photocell to the other lead of the audio cable.



The Activity:

1. Begin with a class discussion about light. Ask the students to describe what they know about light -- ask them what happens when light passes through a prism, what makes a rainbow, etc. Invite them to describe or define terms: white light, visible light, frequency, wavelength, colors, reflect, refract, absorb.

2. Turn on the overhead projector and explain that you are using a diffraction grating to break up the projector's white light into its colors—its spectrum. The diffraction gradient acts like a prism. Ask the students to identify which colors they see.

Some students may have partial or complete color-blindness. Depending on the severity of the condition, some of the color-related activities may be difficult for them.

Be prepared for the possibility that your students may be unaware that they are color-blind. They may be disturbed by this discovery. Alternately, if the student is comfortable with discussing their vision, it may also be a useful point of discussion and observation.

3. Pick a student to place pieces of masking tape on the wall where the red light begins and ends. Ask other students to do the same for the other colors of light.

   Are the marks in the "right" place? If not, why not? Does everyone see colors exactly the same way? [Individuals see variations in colors differently, so students may have differing opinions on where the tape should be.]

4. Ask the students to predict what they will see when they look at the spectrum with their color eyeshades.

   Which colors will "come through?"

5. Invite the students to observe the spectrum through their color eyeshades and describe which colors they can see and which colors have disappeared.

   What do they see? [Red and orange light will be easily seen through the red eyeshades, but green and blue light will not; blue will be easily seen through the blue eyeshades, but red and orange will not.]

To maintain standards of hygiene, the students should not share eyeshades.

For their safety, students wearing dark colored gels should remain seated.

Remind the students never to look directly at the Sun with their eyeshades; even dark eyeshades will not protect their eyes.

6. Experiment with the light. Hold a sheet of colored construction paper against the wall so that part of the spectrum is projected onto the paper. Invite the students to describe (without their eyeshades) any changes they see in the spectrum. Repeat with other colors of paper. After two colors have been used, invite the students to predict what they will see when for particular colors of paper. After sharing their predictions, students should test them. In general, colors of light should still be visible when reflected off a similar color paper, but will be absorbed when a dark, different color paper is used.

7. As a class, invite the students to share explanations of their observations. Students may suggest that their eyeshades act as filters, blocking some colors of light, but allowing other colors of light through to be seen. Other students may guess that the filters have added color to the lights.

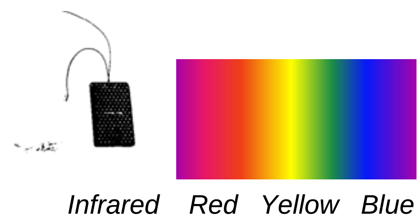
8. Invite the other students to add any points that may support or refute the ideas. For instance, if the eyeshades were adding color, then a red eyeshade should turn the

entire spectrum of light red, rather than simply making some of the spectrum disappear.

9. Share with the students that you are going to use an instrument to examine the light. Show the students the photocell detector/ audio receiver and switch it on. Demonstrate that the amplifier/speaker emits a noise when the photocell is placed in front of a light, such as the projector light, and that the noise is louder when the light is interrupted by a small fan (the instrument is sensitive to changes in light levels). Then slowly pass the photocell in front of the spectrum that is being projected on the wall, holding the fan in front of the photocell.

    Which colors or frequencies of light can the photocell detect? Are there any visible colors that it cannot detect? [It does not detect the purple light as well as the other colors.]

    How does the detector respond when it is moved from yellow to orange to red and beyond? Does the detector make noise when it is in the 'black' area beyond the red light? Can it still detect light? What type of light could that be? [The photocell is sensitive to infrared light.]



Infrared Camera Experiment **(Optional)**

10. Let the students know that there are also cameras that can see infrared light. Turn on the video projector with the infrared camera attached, and point the camera at different objects in the room, allowing the students to see its view. Describe the camera as a visible and infrared camera sensitive to low light levels, and ask the students what that means.

11. Point the infrared camera at the projected spectrum on the wall and tell the students that the camera is overloaded by the amount of light. Tell the students you are going to put color filters in front of the camera, and invite them to predict what the camera will see.

    What will the camera see through a blue filter? [It will show light where the blue part of the spectrum is, and some red light, and infrared light.]

    What will the camera see through a deep red filter? [It will show only red and infrared light.]

    What will the camera see through a blue and red filter together? [It will show a little of the deep red light, and infrared light.]

12. Find a remote control for a TV, VCR, DVD, etc. Observe it with the infrared camera, while pushing buttons on the remote control.

What does the camera show about the remote controller? [When in use, the controller emits light (infrared) that the camera can detect.]

Why would a TV remote controller emit infrared light? [So it won't interfere with your viewing pleasure.]

13. Spend time after all of the observations to analyze and synthesize the students' thoughts and understanding.

    What do the students think the point of the activity was? [Answers may vary greatly, but should include the terms "light" and "spectrum".]

    Which aspects of science did the students do today? [Answers could include using technology, making observations, making predictions, testing predictions, and forming hypotheses.]

    What is a spectrum? How did your class create one? [A spectrum is white light spread out into its component colors. The class created a spectrum using an overhead projector as the source of white light, and a diffraction grating to spread the light out into different colors.]

    What did the filters do to the spectrum of light? [The filters absorbed some of the colors of light and only allowed a few of the colors to pass through. Introduce the term "absorption" if the students haven't used it yet.]

    What happened to the light from the spectrum when it hit the colored construction paper? [Some of the light was absorbed by the construction paper, so it could not be seen.]

    Are there parts of the spectrum that humans can't see? Which parts of the spectrum can our eyes detect? ([We can see the visible light—red, orange, yellow, green, blue, and violet. We cannot see infrared light, and other types of radiation. Invite the students to name other types of radiation, such as x-rays, UV or ultraviolet light, radio waves, and gamma rays.]

    If your class had an ultraviolet camera, where should the students point it to look for ultraviolet light in our spectrum? [We would look past the blue end of the spectrum.]

    In what way could looking at objects in different colors or frequencies give us useful information? Can the students think of times we use different colors of light, or wavelengths that are invisible to us to look at objects? [Examples include having x-rays to check for broken bones, or using ultraviolet light at a crime scene to check for clues. Some students may have seen pictures of stars, planets, or galaxies in x-rays, infra-red, or other wavelengths.]

Extensions

Active Astronomy developed for the SOFIA mission includes additional activities on the spectrum and on transforming energy from one form to another.
http://www.sofia.usra.edu/Edu/materials/activeAstronomy/activeAstronomy.html

Background

Properties of Light

White light, such as light from the Sun or from an overhead projector, is made up of different wavelengths of light, some of which we can see, and some of which are invisible to our eyes. Certain materials (e.g., a diffraction grating, a prism, a raindrop) will refract or bend the light and separate the wavelengths, allowing us to see a variety of colors separately.

The wavelength of light is directly related to energy; red light has a longer wavelength and less energy than yellow light, while green light has a shorter wavelength and more energy, and blue/violet light has the highest energy and shortest wavelength of the visible spectrum.

Many students do not realize that radiation is another term for light, and that there are many types of radiation or wavelengths of light that we cannot see. Radio waves are a type of light, with the longest wavelength, followed by infrared light, then visible light, then ultraviolet light. The shortest wavelengths of light are x-rays and gamma rays. Each of these is a type of radiation—a different range of wavelengths of light.

A wavelength of light has an associated frequency. Red light, with its longer wavelength, has a lower frequency than yellow light. Blue light has a still higher frequency and a shorter wavelength. Ultraviolet light has even shorter wavelengths, more energy, and higher frequencies. Gamma rays have the highest frequencies and energy and the shortest wavelengths, while radio waves have the lowest frequencies and energy, and the longest wavelengths.

Photocell Detector / Receiver Circuit

The receiver circuit uses a photocell to detect the IR signal and convert it back to an electrical signal for the speaker. The photocell (or solar cell) produces an electric current when exposed to light. Because of the way speakers are constructed, a changing current is needed to produce a sound in the speaker; a constant current will not produce a sound. When a constant light source illuminates the photocell, it produces a constant current and no sound is produced. Students should hear static, if anything, when a constant light source illuminates the photocell. When the light changes in brightness, the current produced by the photocell also changes accordingly, and the speaker will produce a sound. If the light is turned on and off (as happens if you move your hand back and forth in the beam of light), you will hear series of “pops” each time the light is turned back on. If the light varies because of a changing electrical current from an audio source, you will hear music from the speaker.

Activity C: Introduction to the ALTA Reflectance Spectrometer

Overview

In this 60 minute activity, students use the ALTA reflectance spectrometer to take readings of different colored objects at different wavelengths, and graph a reflectance spectrum for those objects. Students compare their reflectance spectra graphs and observe that different objects have different spectra.

Learning Objectives:

The student will:

- record measurements of the amount of light reflecting from a surface using an ALTA reflectance spectrometer.
- construct a graph from the reflectance spectrum data.
- compare reflectance spectra.
- predict that different objects have their own unique spectra.

Key Concepts:

- The ALTA Reflectance Spectrometer can be used to measure the amount of light that is reflected off of an object at 11 specific wavelengths.
- The data can be used to construct a graph of the reflectance spectrum for an object.
- Each object has its own unique reflectance spectrum.
- Scientific investigation includes observations, gathering, analyzing, and interpreting data, and using technology to gather data.

Materials:

For the class:

- An ink pad
- Baby or kids wipes, or access to a sink and soap

For each group of 3 to 4 students:

- Copies of the Fingerprint Form
- Familiar materials for the students to analyze, such as a colored construction paper, a variety of fabrics, magazines, etc.
- A small sample (2 tablespoons) of Lunar Soil Simulant
- A small sample (2 tablespoons) of white sand
- 2 sheets of white paper such as copier paper
- 1 ALTA reflectance spectrometer
- 1 Calculator
- 2 copies of the *Reflectance Worksheet*
- 2 copies of the *Spectrum Graph*

Preparation:
1. Plan to break your class into groups of 3-4 students each, with one ALTA spectrometer per group.

2. Check each ALTA reflectance spectrometer—make sure that it has a battery in it, and that numbers appear on the digital display when you turn it on.

The Activity
1. Invite the students to describe how they can identify someone. Hold a brief class discussion on ways we use to identify people. Discussion may include appearance, photo identification cards like driver's licenses, their knowledge of personal information, and fingerprints.

2. Divide the class into groups of 3 to 8 students. Pass out a fingerprint card to each group, and pass around 1-3 ink pads. Ask the students to each use an ink pad to ink either their thumbs and slowly press their thumb into one of the boxes on their fingerprint card.

3. Ask each group to hold a quick discussion.

   What are some of the similarities for some of their fingerprints? What are some of the differences? Can they identify at least two different characteristics for fingerprints? Can they group the fingerprints by characteristics?

4. Let your class know that materials also have a type of fingerprint—each material has a characteristic "reflectance spectrum." Scientists can use this information from a distance to identify substances, such as minerals.

5. Give each group of 4 students an ALTA spectrometer. Ask the students to turn on the ALTA spectrometer. Some of the spectrometers may turn themselves off immediately; the students will need to play with the on/off button until it stays on. If there is no reading on the digital display, the spectrometer is off.

   What do the students see on the back of the spectrometer? [There is a circle of 11 little lights—LED's (light-emitting diodes)—with another similar-looking object in the middle.]

   What do the students see on the front of the spectrometer? [There are 11 buttons, in addition to the On/Off button, each with a different color and a different number—that color's wavelength.]

6. Ask the students to experiment with pushing the different buttons on the front, and observing the led's on the back. If they are having difficulty pushing the buttons hard enough or holding down the buttons, recommend that they use a pencil eraser to push the buttons.

What do the students see when they push the "blue" button after turning it on? [The blue led on the back lights up and remains lit while you hold the button down.]

What happens when they push one of the "IR" buttons on the front? [One of the infrared led's on the back "lights up" but at a wavelength our eyes cannot see.]

7. Ask the students to observe the numbers on the front.

    What do the numbers do when the students hold the bottom of the ALTA over a desk or book? What happens when students hold it up in the air? [The numbers change and increase with increased brightness, until they overload the detector—at which point the ALTA gives a "1".]

    What do the numbers do when the students cover up the back? [They go down.]

8. Ask the students to place the ALTA flat onto a surface (such as a book, a coat…) and push two or three of the buttons (one at a time) and look at the numbers. Ask them to then place the ALTA onto a white piece of paper and repeat the same buttons, comparing the numbers.

    How were the numbers different? [The numbers should be much higher for the white piece of paper.]

    What could the reflectance spectrometer be measuring? [Answers may include "color" or "brightness" or "light;" a better answer is the amount of light that is reflecting off of an object.]

    Which part of the ALTA could be taking the measurements? [The object in the center of the led's on the back is a detector, measuring the amount of light that is entering it.]

9. Share with the students that the light detector measures the amount of light it receives, and displays that amount as a number on the front of the ALTA, measured as voltage.

    Why are the numbers higher when the ALTA is held up in the air? [Light from the room is entering the detector.]

    Why are the numbers so low when the ALTA is completely covered up? [No light is getting into the detector. The number that each ALTA reads when it is receiving absolutely no light is called its "Dark Voltage".]

    Do the ALTAs have the same numbers for the "Dark Voltage"? [Each ALTA detector will be slightly different, producing different numbers.]

Why are there different colors of light bulbs that turn on when you press the buttons on the front? [The different colors can emit specific wavelengths of light, which will reflect off of a surface and into the detector, so that we can measure how well an object reflects that particular wavelength of light.]

Why are the numbers higher for a white sheet of paper than a dark object? [More light is bouncing off of – reflecting from - the paper and into the detector.]

10. Invite the groups to collect spectra for different objects. To do this, they will collect readings of different wavelengths of light reflecting off of objects, and then graph the data. Give each student a copy of the *Reflectance Worksheet* and the *Spectrum Graph* and ask them to write their names and a description of their material.

11. Inform your students that they will need a standard or calibration for their ALTAs. One way to measure how much light of each wavelength is being reflected is to measure the <u>percentage</u> of light reflected, by comparing the light reflected from an object to the light reflected from a bright standard material, such as white paper. Direct the students, working in groups, to place their ALTA flat down on two stacked sheets of blank white paper and press the different wavelengths (colors) one at a time. All of the students in each group should record the numbers for each of the 11 wavelengths on their *Reflectance Worksheets*. Note: if the readings are changing (dropping) rapidly, direct the students to record the first high number.

12. Students should also record the “dark voltage”—the number displayed when none of the buttons are being pushed and the ALTA’s detector is completely covered.

13. Next, the groups should place the ALTA directly onto the materials they are analyzing, and push the different wavelengths (colors) one at a time, and record the number for each of the 11 frequencies on their *Reflectance Worksheets*. Students in the groups can share roles: the group data recorder, the ALTA user, the calculator, and the grapher.

14. Using the calculators, have the groups determine what the percentage of reflectance is for their material for each of the 11 frequencies, by following the calculations on their *Reflectance Worksheet*.

15. The students should fill out their *Spectrum Graph* with the final numbers from their *Reflectance Worksheet*. Discuss graphing as a class or model one example of a spectrum graph if the students have limited graphing experience.

    Where is the x-axis for the graphs? What does it indicate? [The horizontal x-axis indicates different frequencies of light.]

    Where is the y-axis for the graphs? What does it indicate? [The vertical y-axis indicates the percentage of light reflected off of their object.]

Do the students' graphs have any peaks or high points? If so, at which wavelengths? What does that tell them about the objects? [Objects <u>reflect</u> more of the light at those wavelengths; red objects will reflect more red and orange light, for instance.]

Do the students' graphs have any valleys or low points? If so, what does that tell them about the objects? [The objects <u>absorb</u> most of the light at those wavelengths.]

16. Invite each group (one at a time) to present their results, then as a class discuss the similarities and differences in their spectra of the material.

    Do any materials have identical spectra or does each have a different spectrum? [Although some of the spectra may be similar, different materials should have different spectra. However, with only 11 data points, the ALTA cannot always show these differences.]

17. Invite the students to reflect on the activity and analyze their results.

    What do the students think the point of this activity was? [Answers could include taking data and learning to use the ALTA, or may even include learning about the spectrum and learning about light.]

    Which aspects of science did your students do today? [Answers could include using technology, collecting data, putting those data into a readable format – a graph, making predictions and testing predictions.]

    How did each student's spectrum compare to the others in his or her group? How did the different groups' spectra compare to each other? [Different objects have different spectral "fingerprints" – each object had a unique spectral graph.]

    What does the ALTA record? How might this be useful? [The ALTA measures the amount of light that is reflected off of an object, for different wavelengths of light. Scientists could use the reflectance spectrum to identify a mysterious substance.]

    How is the ALTA similar to the human eye? [Both the human eye and the ALTA can measure the amount of light we see, at different wavelengths or colors of light.]

    In what ways can the ALTA detect more than we can? [It can detect four different infrared wavelengths.]

    How could the ALTA be improved to collect more data about the spectrum of an object? [More wavelengths could be could be added.]

How might spectrometers on spacecraft help us learn about other planets? [It is much easier to fly an instrument like a spectrometer past a planet than landing on that planet. Spectrometers can take reflectance spectra of those planets to help us identify what they are made of.]

Background

The ALTA Reflectance Spectrometer

Each frequency or color of light has an associated wavelength. On the ALTA spectrometer, there are LEDs that emit specific wavelengths of light, which can reflect off of a surface. The shortest wavelength for the ALTA is emitted by a blue LED at 470 nanometers (nm) (4.7×10^{-7}m), and the longest wavelength is emitted by an infrared LED at 940 nanometers (9.4×10^{-7}m).

Each ALTA is slightly different, due to variations in the electrical components, lamps, and light sensors, so each ALTA has its own unique sensitivity to different wavelengths of light. Readings can change over time, due to temperature and other variables.

Using the ALTA

When measuring an object's reflectance using the ALTA, the students should hold down the ALTA and see if the dark voltage (the reading without any of the LED's turned on) is within one or two numbers as the dark voltage they had when the ALTA was pressed against a flat surface. If it is not, then outside light is getting in, and they should re-position the ALTA until the numbers are close to the dark reading, before they begin to press other buttons.

Some of the buttons on the ALTA need to be pressed hard to turn on the LED; if students' data seem unusual (if multiple readings are around 20-30) ask them to try again. If students have difficulty pressing or holding the button down, have them use the eraser end of a pencil to push the buttons.

Fingerprint Chart

Names of Scientists on Team

A ____________________________ B ____________________________

C ____________________________ D ____________________________

E ____________________________ F ____________________________

G ____________________________ H ____________________________

A		**B**		**C**		**D**	
E		**F**		**G**		**H**	

Descriptions of key characteristics of fingerprints:

____

____

____

____

Group by characteristics:

1st group: ____________________________

2nd group: ____________________________

3rd group: ____________________________

4th group: ____________________________

Reflectance Worksheet

Names of Scientists on Team

______________________________ ______________________________

______________________________ ______________________________

Sample Description ______________________________

____

____

Dark Voltage Constant ______________________________

Color	Wavelength in Nanno-meters	White Paper Reading	Dark Voltage Constant	White Paper - Dark Voltage (A)		Sample Reading	Dark Voltage Constant	Sample - Dark Voltage (B)		B / A *or* [Sample – Dark V] / [White – Dark V]
Blue	470									
Cyan	525									
Green	560									
Yellow	585									
Orange	600									
Red	645									
Deep Red	700									
Infrared 1	735									
Infrared 2	810									
Infrared 3	880									
Infrared 4	940									

Activity D: Spectrometers in Action

Overview

In this 25 minute activity, students collect reflectance spectra and discover that objects that appear similar can have different spectra. Students discuss the advantages of a high-resolution spectrum to identify objects, and learn about the Moon Mineralogy Mapper / Chandrayaan-1 mission.

Learning Objectives:

The student will:

- collect data and graph the spectra of two different substances that look alike, using the ALTA spectrometer.
- compare the different spectra.
- infer the potential uses of reflectance data.

Key Concepts:

- Each object has a unique reflectance spectrum.
- Data from a reflectance spectrum can be used by scientists to identify objects remotely.
- The Moon Mineralogy Mapper will be used remotely by scientists to analyze rocks on the surface of the Moon.
- Scientific investigation includes observations, gathering, analyzing, and interpreting data, and using technology to gather data.

Materials

For each group of 3-4 students:

- 2 copies of the *Reflectance Worksheet*
- 2 copies of the *Spectrum Graph*
- 2 sheets of white or bright construction paper
- 1 sheet of black construction paper [*Note: do not use black cardstock; it may not work for this experiment.*]
- 1 black markers
- 1 ALTA reflectance spectrometers
- 1 calculator

Preparation:

1. Test your black construction paper ahead of time; look at the infrared reflectance raw numbers. If they are lower than 200, you will need a different type of construction paper. Many types of black construction paper yield numbers higher than 800 for infrared voltages.

2. Cut one small square, about 5 by 5 centimeters (2 by 2 inches), out of black construction paper.

3. Draw a similar-sized square using black marker on white construction paper. Fill it in and cut the square out.

4. Check each ALTA reflectance spectrometer—make sure they are working properly.

The Activity

1. Holding up the two black squares you prepared in advance, ask your students to identify the difference between the pieces of paper.

   Can your students at the back of the room tell the difference? What about the students at the front of the room?

   Are there times when scientists would like to examine something that is too far away for them to touch? Can the students name examples? [.Scientists might want to examine moons, planets, and stars to learn more about them.]

2. Divide your class into groups of 3-4 students each. Give each group an ALTA, two *Reflectance Worksheets,* two *Spectrum Graphs*, a sheet of black construction paper, a sheet of white construction paper, two calculators, and a black marker.

3. Ask each group to color part of the white construction paper with the black marker, so that at a 5 by 5 centimeter (2 by 2 inch) section is completely black.

4. Ask the students to predict what the spectrum of the construction paper will look like, and whether the construction paper that has been colored black with marker will look similar or different. Students may suggest that there will be low numbers—low reflectance—for most wavelengths.

5. Have the groups determine which student will be conducting which task. One person will be needed to use the reflectance spectrometer, one to record the data, one to compute the numbers, and one to graph the results.

6. The groups should collect reflectance data from the white construction paper or plain white paper with their ALTA, as in the last activity, to have a standard for comparison. They should also record the dark voltage for their ALTA.

7. Invite the teams to collect and graph the reflectance data for the black construction paper and the black-colored white construction paper.

8. As a class, invite the students to share their results and analyze their conclusions.

   Are the spectra similar or different? If there are differences, what can they be attributed to? [The spectra with black marker are much lower in the infrared range than the black construction paper. The chemicals in the black marker are darker in infrared.]

Can two substances that look alike have different spectra? [Yes they can—particularly at wavelengths that our eyes can't see. Materials made of different chemicals will absorb different wavelengths of light. Objects with identical chemical makeup have identical spectra.]

What do the students think the point of this activity was? [Answers could include that objects which look alike can have very different spectral measurements.]

*Which aspects of science did your students do today? [*Answers could include making a discovery, using technology, taking data, making predictions and testing predictions.]

We discovered that different materials have different spectra, even when they look alike. How might this be a useful tool on the Moon or Mars? [Scientists can use this to help identify different materials, like rocks, minerals, and resources.]

9. Compare the range of wavelengths visible to humans, to the wavelengths taken by the ALTA spectrometer.

   What colors do most humans see? How many different shades of color can people see? [People see visible light. The cones in human eyes can detect red, green and blue, but our brains use that information to detect differences between hundreds to thousands of different shades of color.]

   In what ways can the ALTA detect more than our own spectrometers – our eyes – can see? [It can measure four different infrared wavelengths.]

   In what ways is the ALTA limited? How could it collect more information, and why would those changes be useful? [The ALTA can only give us a spectrum with 11 data points—11 wavelengths. More wavelengths would give us more details, and make it easier for scientists to identify specific materials.]

   How might spectrometers on spacecraft help us learn about other planets? [Spectrometers could take reflectance spectra of materials on those planets to help us identify them.]

10. Describe a specialized spectrometer that can measure 261 different wavelengths, which together cover all of the visible spectrum and the near-infrared wavelengths.

    How would a more detailed spectrum help scientists? [It would make it easier to identify the types of rocks and minerals on the Moon.]

11. Describe the Moon Mineralogy Mapper (M^3), a spectrometer that will be flown on Chandrayaan-1 to orbit the Moon and take a detailed spectrum of the different points of the Moon's surface. Ask your students how this would provide more information about the Moon.

Background

Colored Materials

Paper, marker, and crayon have different colors because different pigments have been added to the original materials. Different types of black construction paper may have different reflectance spectra because of the different processes used to make them black.

Facilitator Background: The Moon Mineralogy Mapper (M^3)/ Chandrayaan-1

Moon Mineralogy Mapper (M^3) is one of two instruments that NASA is contributing to India's first mission to the Moon, Chandrayaan-1, which is scheduled to be launched in 2008. M^3 will provide the first spectroscopic map of the entire lunar surface at high resolution, revealing the minerals of which it is made.

The instrument will detect electromagnetic radiation with wavelengths from 430 to 3000 nanometers (0.43 to 3 microns), which covers visible light and the near-infrared. M^3 will divide the approximately 2600 nanometer range to which it is sensitive into 261 discrete bands, each of which is only 10 nanometers wide. This is considered very high spectral resolution, and will enable M^3 to detect the fine detail required for mineral identification. Spatial resolution will be similarly high. From its vantage point 100 kilometers above the lunar surface, M^3 will be able to resolve features as small as 70 meters in size.

The individual spectra collected by M^3 will be combined to form a detailed picture or map of the lunar surface. Each picture or map that M^3 produces will show mountains, craters, or plains like a regular camera, but in a very narrow range of wavelengths (the 10-nanometer sliver of the spectrum that constitutes one spectral channel). It's like taking a picture using a filter that allows only one precise color of light through the lens (similar to Activities 1 and 2). But M^3 will take 261 such pictures simultaneously, each in its own "color." To identify the spectral fingerprint of a particular portion of the lunar surface, one would plot the light intensity of each of the 261 channels, noting how bright each pixel is at each wavelength. Plotting this on a graph produces a spectrum. Each mineral has its own unique spectrum, identified by taking spectrographic readings in a laboratory.

The accompanying slide show will provide some more information and background material on the mission and why we are going back to the Moon.

For more information, go to
http://moonmineralogymapper.jpl.nasa.gov/INSTRUMENT/

Reflectance Worksheet

Names of Scientists on Team

______________________________ ______________________________

______________________________ ______________________________

Sample Description ____

____

____

Dark Voltage Constant ____________________

Color	Wavelength in Nanno-meters	White Paper Reading	Dark Voltage	White Paper - Dark Voltage (A)		Sample Reading	Dark Voltage	Sample - Dark Voltage (B)		**B / A** ***or*** [Sample – Dark V] / [White – Dark V]
Blue	470									
Cyan	525									
Green	560									
Yellow	585									
Orange	600									
Red	645									
Deep Red	700									
Infrared 1	735									
Infrared 2	810									
Infrared 3	880									
Infrared 4	940									

Module 2

In this module, students will demonstrate the advantage of spectroscopic data and will make connections to the Moon. We strongly recommend that introductory ALTA activities from Module 1 are done before attempting Activity B.

Activity A: Observing the Moon (50 minutes)
Students observe images of the Moon at various wavelengths. Students deduct that the various types of light are sunlight reflected from the surface of the Moon. Students observe that some features are more readily seen at certain wavelengths. Students discuss the limitations of our current data from the Moon, and the plans for the M3 Mapper

Activity B: Remote Analysis of the Moon (60 minutes)
Students break up into teams of “Orbiters” and “Earth scientists” to gather reflectance data from “Moon rocks” and Earth rocks respectively. Students compare the reflectance spectra from their Moon samples to the spectra from known Earth rocks to identify the rock types on the Moon.

Activity A: Observing the Moon

Overview

In this 50 minute activity, students observe images of the Moon at various wavelengths. Students deduct that the various types of light are sunlight reflected from the surface of the Moon. Students observe that some features are more readily seen at certain wavelengths. Students discuss the limitations of our current data from the Moon, and the plans for the M3 Mapper.

Learning Objectives:

The student will:

- identify light from the Sun as the source of the Moon's radiation.
- contrast the Moon's appearance at different wavelengths of light.
- compare future planned missions examining the Moon's surface with past missions and how the data will differ in resolution and detail.

Key Concepts:

- The Moon can be viewed in many different wavelengths of light, because it is lit by sunlight is reflected off of its surface, and sunlight includes all these wavelengths.
- The Moon's surface is not uniform; there are various features visible at different wavelengths of light.
- Spectra for the different rocks on the Moon's surface can be used to identify the rocks and mineral resources on the Moon.
- The Apollo mission gathered samples of Moon rocks that scientists have examined and studied spectroscopically.
- The Galileo and Clementine missions gathered spectroscopic data on the Moon, with limited resolution, at limited wavelengths.
- Upcoming missions, including the Chandrayaan-1 with the M3 Mapper, will gather more detailed data about the Moon using spectrometers.

Materials

For the class:

- A color copy of *Images of the Moon* for each student
- A basketball, a baseball, a golf ball, and a marble
- A measuring tape and a ruler

Preparation:

Print out color copies of *Images of the Moon* for individual students or for groups of students, or print out posters for the students to observe, or plan on projecting the images for everyone to see.

The Activity

1. Begin with an open discussion about our exploration of the Moon. NASA is planning future human missions to the Moon.

   What will we need to know about the Moon, before we can build an outpost there? [Among many other things, we will need to know more about the resources on the Moon.]

2. Share NASA's need to know more about the different types of rocks and minerals on the Moon, and that we will eventually use this information to answer questions about what the Moon is made of, how its surface has been altered, and where resources might be located. Tell your students that they are going to examine data of the Moon taken by telescopes and missions.

3. Ask the class about past missions to study the Moon. Students may mention the Apollo astronauts, who collected 842 pounds of rock samples from six locations on the Moon.

4. Let the students watch some of the movie clips of the Apollo missions, then hold a class discussion about the missions and the resulting collections of rock samples.

   How long does it take to get to the Moon? What is it like on the Moon?

   Do the students have opinions on why we haven't visited more of the Moon's surface? [Missions are limited by funding, time, technology, distance…]

   What type of understanding of the Moon do the students think we have from the Apollo rock collection? [Rocks were only collected from 6 locations on the Moon; we have an incomplete picture and there may be many other types of rocks on the Moon.]

   Why are the Moon rocks important in understanding the spectra we get from the Moon? [Having Moon rocks on Earth gives us a basis of comparison for other spectra we may gather from a distance.]

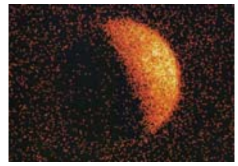
5. Model the scale and distance between the Earth and Moon for your class, using a basketball for the Earth, and a tennis ball as the Moon. Invite the students to guess how far away to place the tennis ball Moon from the basketball at this scale. Use a measuring tape to measure out the distance--23.5 feet away. The Moon is 382,500 kilometers (237,500 miles) away.

   Are there other ways we can get information about the Moon without sending humans to collect samples? [We can take spectra from a spacecraft.]

6. Share that the Moon has been remotely explored by several spacecraft – Galileo, Clementine, the Lunar Prospector, and the Japanese Kaguya. Galileo flew past the Moon twice; Clementine, Lunar Prospector, and Kaguya orbited the Moon.

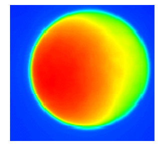
Telescopes have taken photos of the Moon at very different wavelengths. Let the students examine some of the images taken by the missions and telescopes.

How are the images the same? Different? Why are the images different? [The images are taken at different wavelengths, which are sensitive to different features. They are also taken by different instruments with a variety of resolutions. Some are photos of the "full" Moon and others at other Moon phases.]



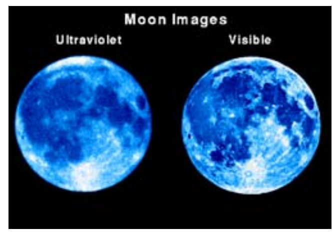
7. Ask the students to examine the Rőntgen Satellite (ROSAT) x-ray photo of the Moon. What do they observe?

   Why is part of it bright and part dark? [The Sun is shining on the part that is bright.]



8. Ask them to examine the Very Large Array (VLA) radio photo of the Moon. Let them know that the red regions have the brightest radio waves and the blue regions have the faintest radio emission.

   Which part of the Moon do they think the Sun was shining on, and why? [The Sun was shining on the left side of the Moon, which is why that side is brighter in radio wavelengths.]



9. Invite them to examine ultraviolet, infrared, and visible light photos of the Moon.

   Are there similarities? Differences? [All the images have brighter and darker regions. The color codes used for the mid-infrared image is different, as are the bright areas on it.]

   Are there patterns to the shapes of the bright and dark areas? [The darker regions are frequently round, and the bright spots are often small and sometimes have rays shooting away from them.]

10. Examine the Spectroscopic Maps from the Galileo Mission with the class. Unlike the photos at one specific range of wavelengths, these maps are made from different photos of the Moon at different wavelengths, stacked together.

    How are these pictures different from the other photos? [There are multiple colors used here for each image; they have more data.]

    Are the colors used the "real" colors of the Moon? [No, the colors are coded for particular 'fingerprints' of brightness of reflected light.]

    Why are there different colors? [The different colors represent regions that were bright at different wavelengths of light, so different colors tell us that those parts of the Moon are made of different minerals.]

11. Examine the Spectroscopic Maps from the Clementine Mission with the class. These maps are made by comparing the Moon's reflectance at specific wavelengths, which gives scientists a fingerprint for particular minerals, like iron.

    Which parts of the Moon have lots of iron? Which parts of the Moon are low in iron?

    If we only had the photo of the Moon in visible light, would we know that the Moon contains iron? [No, we can only determine it by looking at specific wavelengths.]

12. Tell the students about the upcoming missions - the Indian Space Research Organization's upcoming Chandrayaan-1 spacecraft mission, Lunar Reconnaissance Orbiter (LRO), and Selenological and Engineering Explorer (SELENE) also called Kaguya. All of these missions have spectrometers aboard.

    If we already have this information, why are we collecting more? [As we've observed, different wavelengths reveal different features. We need data at a higher resolution to see more specific features, and with many more wavelengths to determine what specific minerals or rocks are there. These missions will also gather data to help us better understand the lunar environment, such as radiation and temperatures.]

    What might the new instruments tell scientists? [Spectrometers will help scientists identify the types of rocks and minerals that are on the surface, where they are, and the amounts.]

13. Discussion: Time for your students to synthesize some of this information.

    What do the students think the point of this activity was? [Answers could include "learning about missions to the Moon," "observing the Moon in different types of light" or may even include "learning about the spectrum" or "learning about light."]

    *Which aspects of science did your students do today? [*Answers could include examining data and making observations.]

    Why might scientists want to observe the Moon using different wavelengths of light? [Different wavelengths of light will make it easier to spot certain features, and if enough wavelengths are used, scientists can get a spectrum of the Moon's surface.]

    How will the upcoming missions help us to understand what the Moon is like? [These missions will take photos at many different wavelengths. Scientists will put together a spectrum for detailed features on the Moon to learn about the types of rocks or minerals on the Moon.]

Extensions

Cool Cosmos has created a wide variety of educational products that explain the infrared as well as the multi-wavelength universe. Further information about the Moon at different wavelengths is available at: http://coolcosmos.ipac.caltech.edu//cosmic_classroom/multiwavelength_astronomy/multiwavelength_museum/moon.html

Background

Sunlight's Role

Many students are not aware that the light we see from the Moon is reflected sunlight. Some of that light heats the Moon, so that it also glows in infrared and radio wavelengths. Your students may also not realize that while most of our Sun's energy is in the form of visible light and infrared light, it also radiates smaller amounts of all of the other wavelengths.

Apollo Lunar Samples

The Apollo astronauts gathered material that scientists on Earth have analyzed. Each trip to the Moon took about 3 days to reach the Moon and another 3 days to return. Between 1969 and 1972 six Apollo missions brought back 382 kilograms (842 pounds) of lunar rocks, core samples, pebbles, sand and dust from the lunar surface. The six space flights returned 2200 separate rock and dust samples from six different exploration sites on the Moon. These samples have been analyzed by scientists to better understand the Moon's composition, formation, structure, and geologic history. The Apollo explorations covered only 95 kilometers (60 miles) of the Moon's surface – a small percentage! Some movie clips are available, as are more information and photos of the rocks.

The Galileo Mission

The Galileo Spacecraft Mission was designed to study Jupiter and its moons, but was able to take useful data about our own Moon during its two fly-bys on the way to Jupiter, (1990 and 1992). *Galileo* provided clearer views of the lunar farside and the north and south polar regions.

The Clementine Mission

The Clementine Spacecraft was a joint project between the Strategic Defense Initiative Organization and NASA. The objective of the mission was to test sensors and spacecraft components under extended exposure to the space environment and to make scientific observations of the Moon. In May and June of 1994, the Clementine spacecraft mapped the Moon's whole surface in 11 different bands of the spectrum, using the ultraviolet-visible (UVVIS) and near-infrared (NIR) camera systems.

Lunar Prospector

In 1998, NASA's Lunar Prospector Spacecraft (LP) conducted a one-year study of the Moon in a polar orbit, dedicated to globally mapping lunar resources, gravity, and magnetic fields, and outgassing events. The mission included five instruments -- the gamma-ray spectrometer, alpha particle spectrometer, neutron spectrometer, magnetometer and electron reflectometer.

SELENE—Kaguya

The Japan Aerospace Exploration Agency (JAXA) plans to launch SELENE (SELenological and ENgineering Explorer) from Tanegashima Space Center in 2007. The major objectives of the SELENE mission are to obtain scientific data of the lunar origin and evolution and to develop the technology for the future lunar exploration. SELENE consists of a satellite which will orbit the Moon at about 100km altitude and two smaller satellites which will go around the Moon in polar orbits.

Lunar Reconnaissance Orbiter

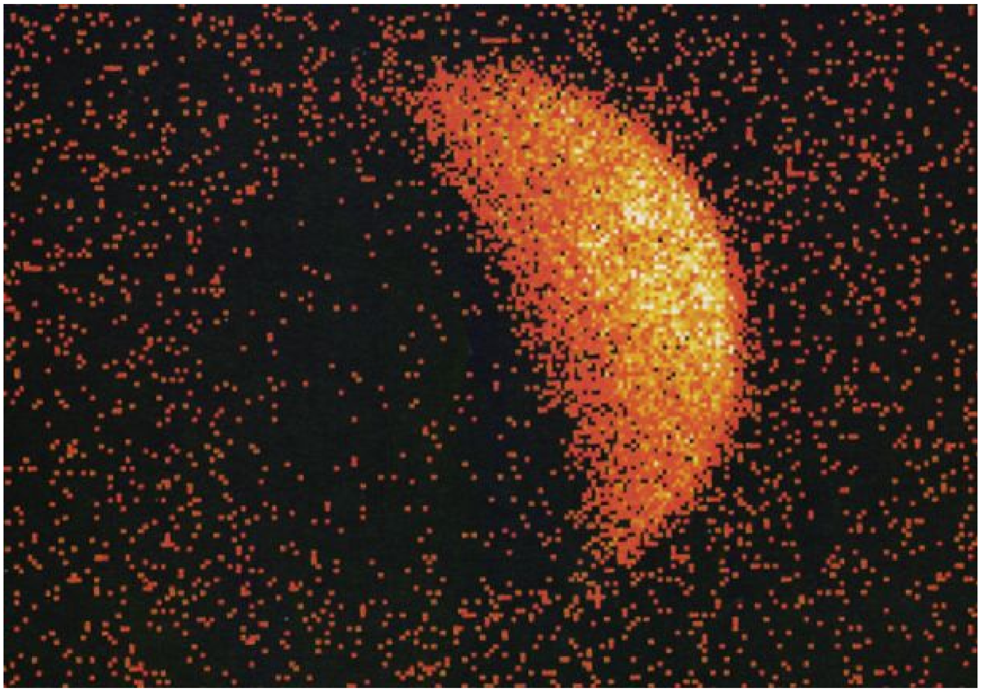
The Lunar Reconnaissance Orbiter, or LRO, is a robotic mission that will orbit the Moon. The LRO is scheduled to be launched in 2008 from Kennedy Space Center. Its primary mission is to spend one year in a polar orbit collecting detailed information about the Moon's environment. The orbiter will have solar arrays and a Lithium-Ion battery for power. It will have a computer and use radio to receive commands and send information back to Earth. Its instruments will study the radiation the Moon receives, map out day and nighttime temperatures, create a high-resolution topographical map, map out valuable resources using reflectance spectroscopy, and more.

Chandrayaan-1

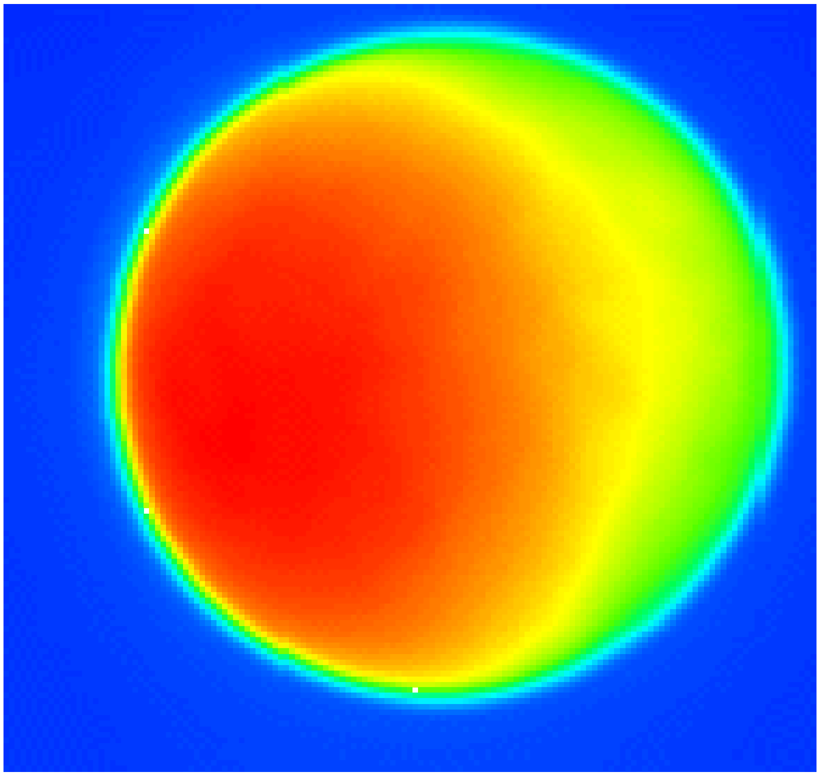
The Indian Space Research Organization (ISRO) will launch the Chandrayaan-1 mission to Moon in late 2007 to further our understanding of the origin and evolution of the Moon. The instruments onboard will provide simultaneous mineralogical, chemical and photo-geological mapping of the lunar surface at resolutions better than previous lunar missions. They will allow scientists to directly estimate the amount of various elements and minerals on the Moon's surface, create a high resolution three-dimensional map of the Moon, and more. Two instruments on the Chandrayaan-1 are being contributed by NASA, including the Moon Mineralogy Mapper (M^3).

Images of the Moon

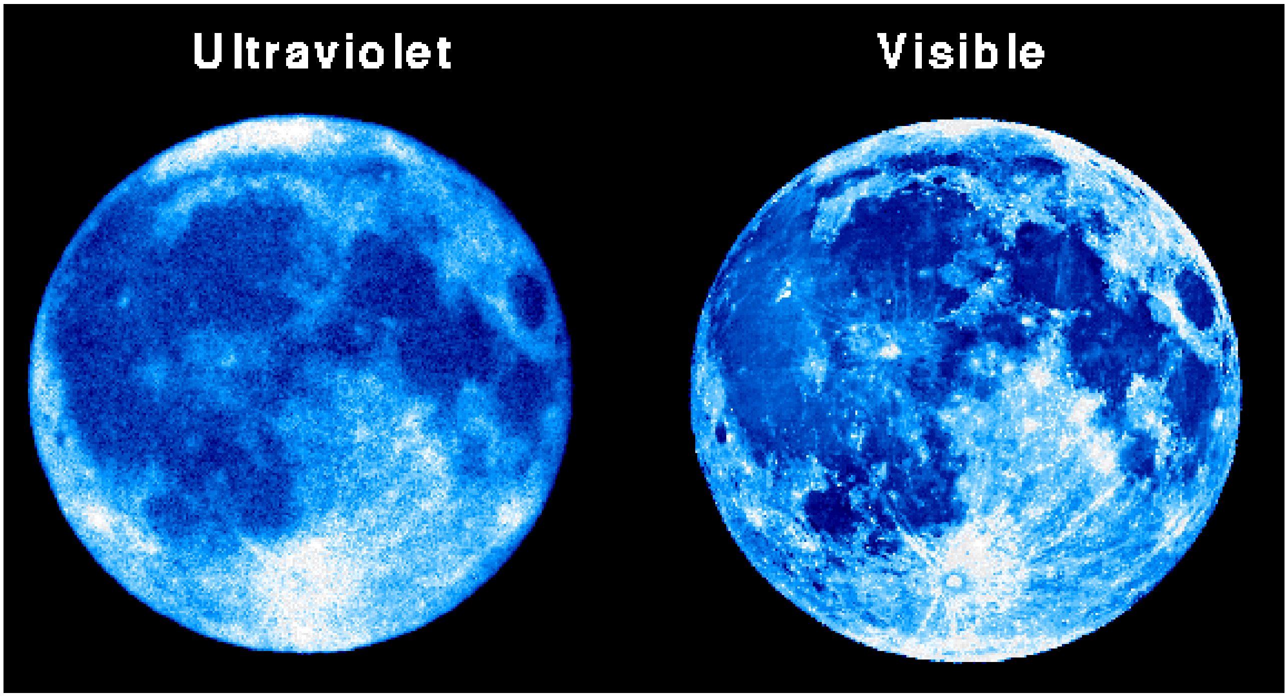
(Source: CoolCosmos: Multi-Wavelength Astronomy: The Moon)



X-ray image of a quarter Moon taken by the Rőntgen Satellite (ROSAT)

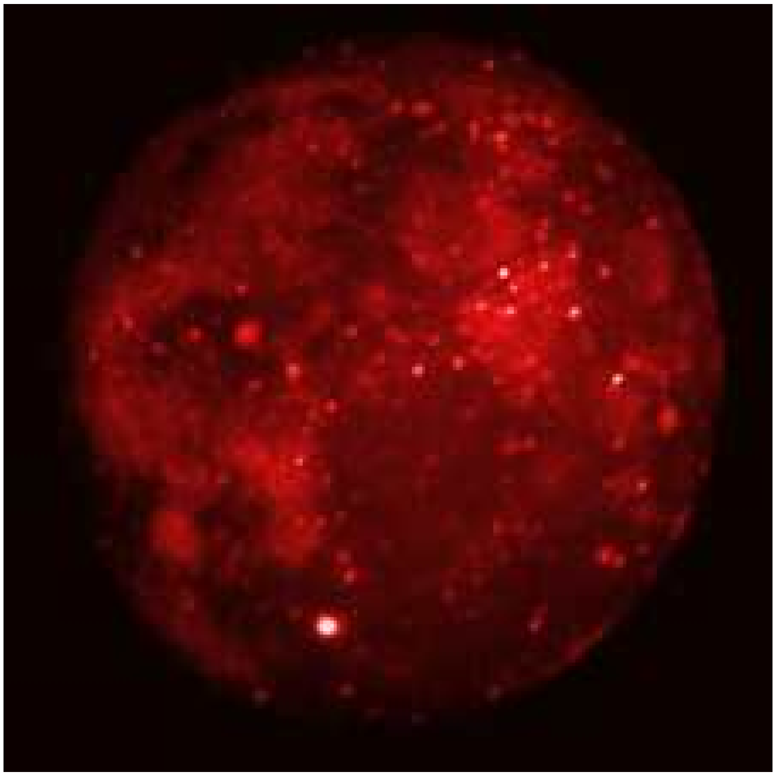


Radio image of the Moon (gibbous phase) taken by the National Radio Astronomy Observatory's Very Large Array (VLA) in New Mexico.



Ultraviolet image of the full Moon taken by the Ultraviolet Imaging Telescope aboard the Space Shuttle Endeavor.

Visible image of the full Moon taken at Lick Observatory.

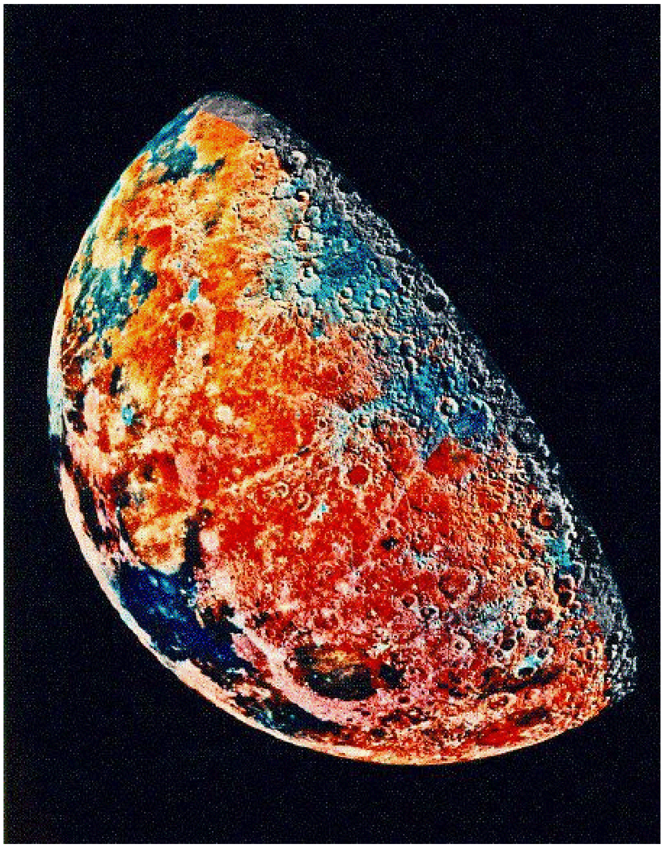


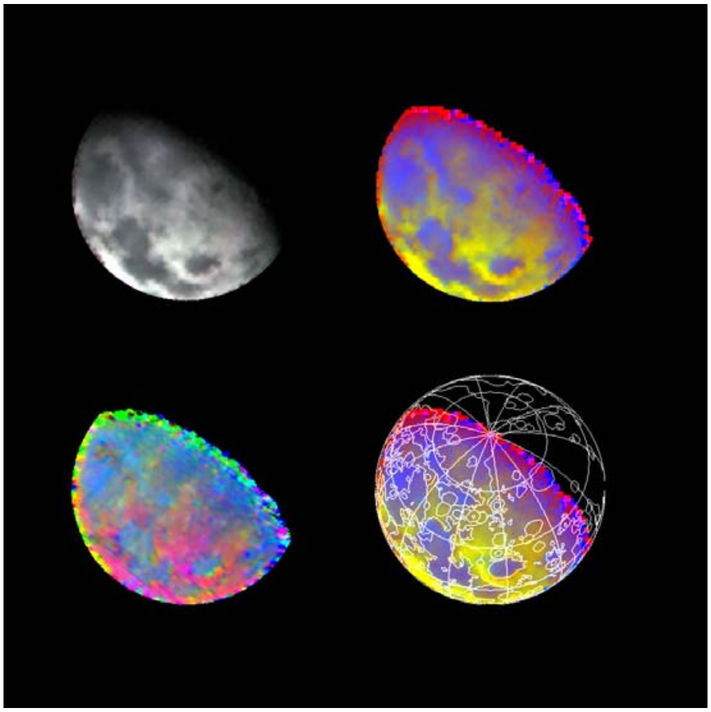
Mid-infrared image of the full Moon during an eclipse, taken by the Midcourse Space Experiment (MSX) satellite.

Spectroscopic Maps from the Galileo Mission

Unlike the photos at one specific range of wavelengths, each map is made from several photos of the Moon at different wavelengths (and color-coded at different colors), stacked together.

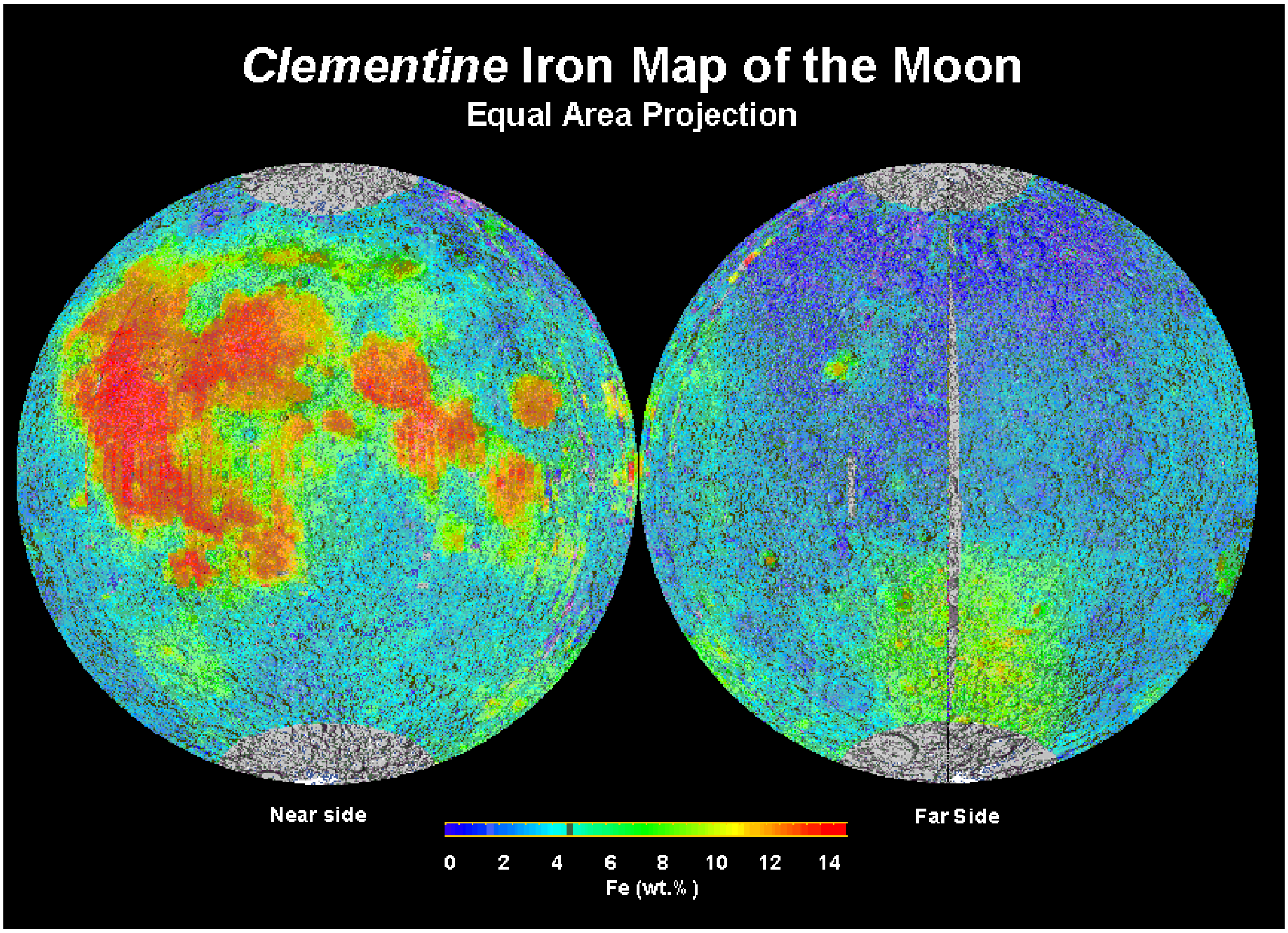
The Galileo mission flew over the Moon at an angle that we cannot see from the Earth.





Spectroscopic Map from the Clementine Mission

Unlike the photos at one specific range of wavelengths, each map is made from several photos of the Moon at different wavelengths (and color-coded at different colors), stacked together.



Activity B: Remote Analysis of the Moon

Overview

In this 60 minute inquiry-based activity, students break up into teams of "Orbiters" and "Earth scientists" to gather reflectance data from "Moon rocks" and Earth rocks respectively. Students compare the reflectance spectra from their Moon samples to the spectra from known Earth rocks to identify the rock types on the Moon.

Learning Objectives:

The student will:

- describe how a reflectance spectrum can be used to identify an unknown substance.
- describe the characteristics of the reflectance spectra of at least three different rocks.
- infer the value of sharing and comparing scientific data.
- infer the value of communicating scientific findings.

Key Concepts:

- Rock types have unique reflectance spectra. Rocks can be identified by their reflectance spectrum or "rock fingerprints".
- Scientific investigation includes making observations, gathering, analyzing, and interpreting data, and using technology to gather data.
- Scientists from different teams or different fields may need to share their data and findings to develop new theories or make sense of observations.

Materials

For the class:

- 1-4 ink pads
- Hand wipes or access to a sink and soap

For each team of 2 to 3 students

- 1 box, large enough to hold 5 or 6 rocks
- 1 ALTA reflectance spectrometer
- 5 copies of the spectrum graph, on transparencies if possible
- 5 copies of the Reflectance Worksheet

For each group of 2 to 3 students (Orbiter Teams)

- Rock samples: all rocks need to be at least 5 by 5 centimeters (2 by 2 inches) wide, with a flat surface
    - 2 basalt rocks
    - 2 anorthosite rocks
    - 1 olivine rock

For each group of 2 to 3 students (Earth Teams)

- Rock samples: all rocks need to be at least 2"x2" wide
  - 1 basalt rock of same type as one of the Orbiter's basalts
  - 1 anorthosite rock of same type as one of the Orbiter's
  - 1 dunite (olivine-rich) rock of same type as one of the Orbiter's
  - 1 rhyolite rock
  - 1 chalk limestone rock

All rocks need to be at least 2"x2" wide (hand specimens), with a flat surface; can be purchased at suppliers such as Wards: basalt (item 47 V 1044), anorthosite (item 47 V 0559), dunite / olivine (item 46 V 5834), rhyolite (item 47 V 6909), chalk limestone (47 V 4664)

Preparation:

1. Arrange your classroom or two separate rooms so that groups can work without observing each other. Your class will work in teams of 2 to 3 students each: half of the teams will be the "Orbiter" teams, and the other half will be the "Earth" teams. The Orbiter teams and Earth teams should not be able to see each others rock samples.

2. Prepare each Orbiter Team box to include an ALTA Spectrometer, 5 copies of the *Reflectance Worksheet,* 5 copies of the *Spectrum Graph,* and 5 rock samples: an anorthosite labeled "Rock Type 1", a basalt labeled "Rock Type 2", 1 dunite (olivine), labeled "Rock Type 3", another basalt labeled "Rock Type 2" and another anorthosite, labeled "Rock Type 1."

3. Prepare each Earth Team box to include an ALTA Spectrometer, 5 copies of *Reflectance Worksheet*, 5 copies of the *Spectrum Graph,* and 5 rock samples, labeled with the correct name: 1 basalt, 1 anorthosite, 1 rhyolite, 1 limestone chalk , and 1 dunite (olivine).

4. Prepare to darken the classroom(s) by closing window blinds.

The Activity

1. Invite the students to share or recall what a reflectance spectrum is-- the amount of light at particular wavelengths that is reflected off of the rocks. Remind your students of the fingerprints they took in Module 1.

   How are finger prints like reflectance spectra? [Just as fingerprints can be used to identify people, reflectance spectra can be used to identify materials.]

2. Tell your students that they are going to simulate a mission to identify the rocks on the Moon. They will be separated into teams, with some team members ("Orbiters")

gathering reflectance spectroscopic data from Moon rocks, and others ("Earth scientists") gathering spectroscopic data from Earth rocks.

After the Orbiter team members and the Earth team members have collected their spectra, they will regroup and compare the spectra. They will not compare the rocks. When spectrometers orbiting the Moon (such as those aboard M3 and other spacecraft) send data back to scientists, there are no pictures of the rocks; the scientists have only the spectral curves to analyze and interpret.

The rocks provided to the "Orbiters" are not real Moon rocks, but are the types of rocks that have been collected by Apollo missions.

> *What will the reflectance spectra tell us?* [Every different type of rock has a different reflectance spectrum. The students will use the spectra to help them identify the rocks on the Moon.]

3. Inform the students that due to their rough and angular nature, there will be differences in collect reflectance measurements of rocks: the overhead lights will be off, and the rock should be large enough to cover the hole at the back of the ALTA. Students should not try to fit a pointed part of the rock into the hole—they should only take measurements from flat surfaces.

4. Organize the class into groups of 4 to 6 students. Then designate half of each group as the "Orbiter team" and half as the "Earth Scientist team." Send the "Orbiter" teams to their work area, and the "Earth scientist" teams to their work area. Bring each of the teams their boxes, with rock samples and an ALTA spectrometer. Instruct the Orbiter teams to take spectra of Rock Samples #1 through 5, representing the rocks observed in different parts of the front face of the Moon. Instruct the Earth Scientist groups to take spectra of their 5 different labeled rock samples. Working in their teams and sharing duties, students should complete a *Spectrum Graph* for each rock sample.

   > *Are there any noticeable patterns? Are any of the spectra high or low? Do any of them have drops or large bumps? Are any of the spectra similar?*

5. Ask the teams of Orbiters and "Earth Scientists" to unite back into their groups (leaving their rock samples behind). Each group should compare their spectra and attempt to classify the Orbiters' rock samples based on the spectra of Earth rocks. Ask the teams not to use descriptions of the rocks to try to classify the Moon rocks.

   > *How do your students describe the spectra?* [Low and flat? Does it rise in the infrared? Does it fall low in the infrared? Does it rise for the blue and then drop?]

   > *Do any of the groups have spectra that match? Do any of the Earth rock samples have spectra that match the Moon rock spectra?*

6. Ask the groups to report on their findings and observations to the class, showing their spectra and describing the matches they have found and some of the spectra of Moon rocks that they have not identified.

   What might be some sources of error or difficulties in identification and matching? [Students may make errors in recording the data, in calculations, or in graphing. Different rocks will vary in reflectance—rocks have natural variations in mineral content. The students may have had difficulty taking a good reading from a rock sample without letting outside light in.]

   Can the students think of ways to reduce their errors? [They could take more readings, or share their results with each other.]

7. Ask the students representing the Earth scientists to meet together and compare their spectra for each of their rock types, laying their transparencies on top of each other to look for patterns. Have the Orbiters do the same. Ask them to identify common characteristics for each of the rock types; if one of the spectra doesn't match the others, they should focus on those that do match.

8. Bring all of the students together and ask the Orbiters to show the spectra and characteristics for rock type #1 through 5. Invite the Earth scientists to suggest which of the Earth rocks each spectrum resembles.

   Do all of the students agree with all of the identifications or are there any disputes? [Remind the students that scientists often debate about new findings.]

   What are some ways to settle these debates? [Scientists look for additional data to confirm or reject their findings.]

9. Hand out copies of the Rock Information Sheet to the students, and ask them to compare its information to their current identifications of the Moon rocks.

   What types of rocks have the students found on the Moon? [anorthosite, basalt, dunite (rich in olivine)]

   Which rock samples from Earth were not found on the Moon? What might this tell your students? [Students should not have found limestone—a sedimentary rock, or rhyolite on the Moon. The Moon has no water or wind to form sedimentary rocks like limestone. Its crust is probably not like Earth's continental crust, so it is unlikely to form rhyolite in explosive volcanic eruptions.]

10. Invite your students to explore their findings.

    What do the students think the point of this activity was? [Answers could include learning about gather data and analyzing it, taking and comparing reflectance spectra, using spectra to identify rocks on the Moon, and learning how scientists identify rocks on other planets and our Moon.]

Which aspects of science did your students do today? [Answers could include making observations, analyzing data, recognizing patterns, devising explanations and evaluating each other's explanations.]

Why are collaboration and sharing data important for science? [Collaboration and sharing data allow scientists to evaluate findings and arrive at more likely conclusions.]

Do scientists have to account for errors? [Yes; scientist examine their work for sources of errors.]

How can taking spectra help us to identify rocks on the Moon and other planets? [Scientists can comparing their spectra to those of known materials.]

How can scientists take better spectra to better identify rocks on the Moon and eliminate more errors? [By taking more detailed spectra, with a larger number of wavelengths and at more infrared and ultraviolet wavelengths.]

Background

Rock Graphs:

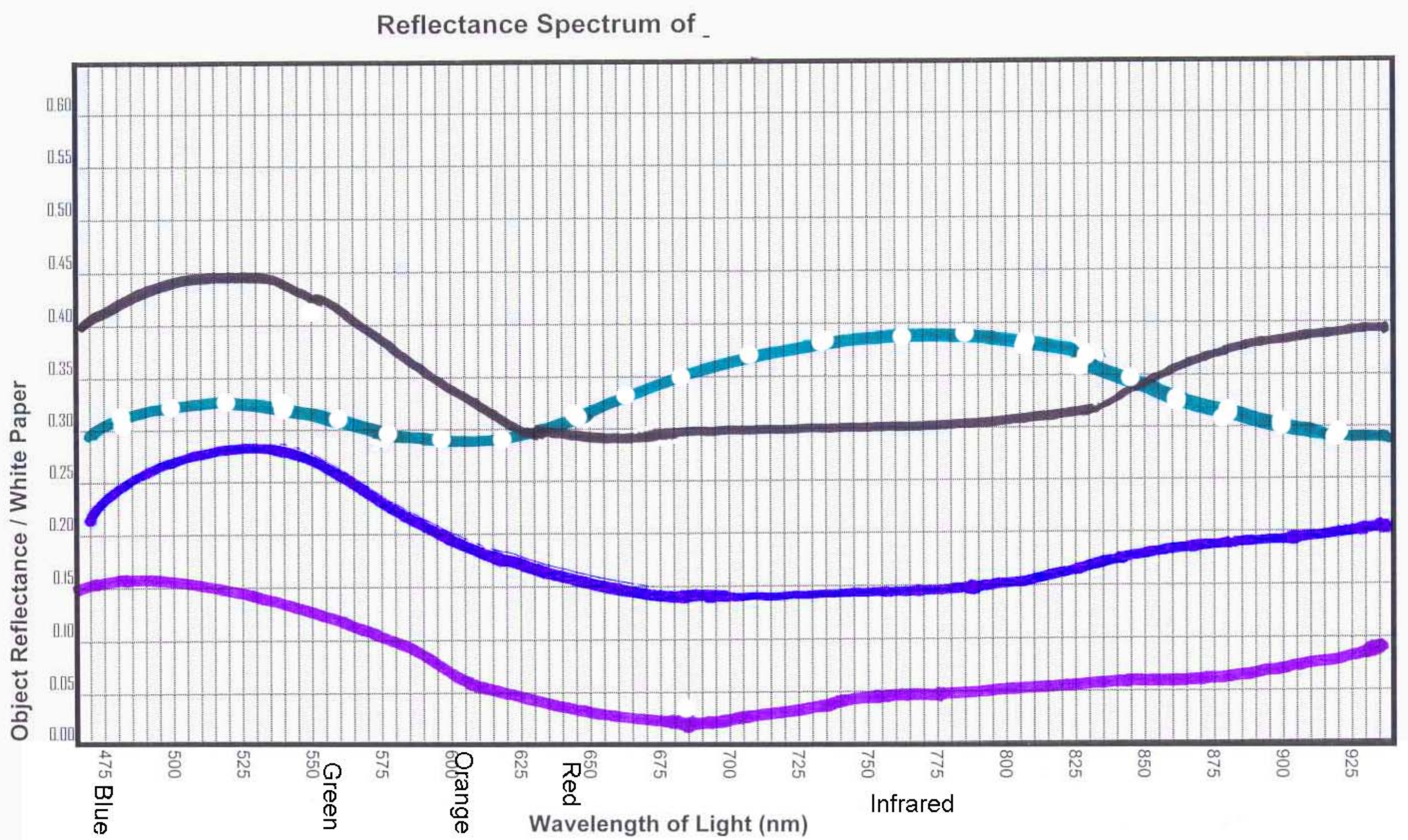
There will be natural variations in each rock sample, and even different sides of the same sample may give slightly different spectra. Rocks and minerals can be better identified by scientists with more detailed spectra that extend further into the infrared than the ALTA or other reasonably-priced classroom spectrometers can reach.

Here are some sample example spectra of the rocks used in this activity: Note: Multiple spectra shown for each rock type, these indicate the slight variations in composition of the rocks.

Anorthosite:

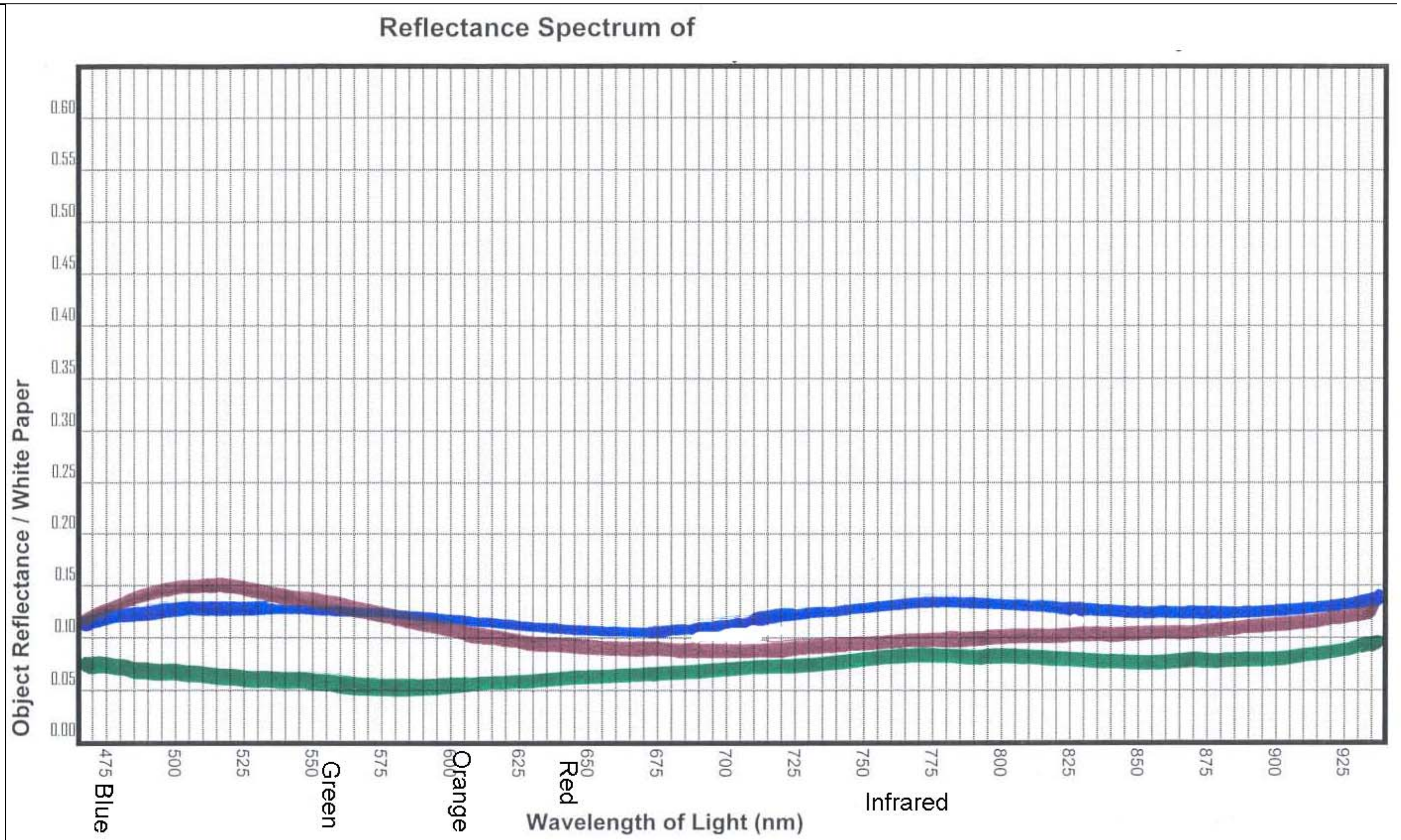
High reflectance, with little variation in wavelength, but there may be large variations from one sample of anorthosite to another, as indicated by the dotted line (which represents a spectrum that doesn't match the pattern).

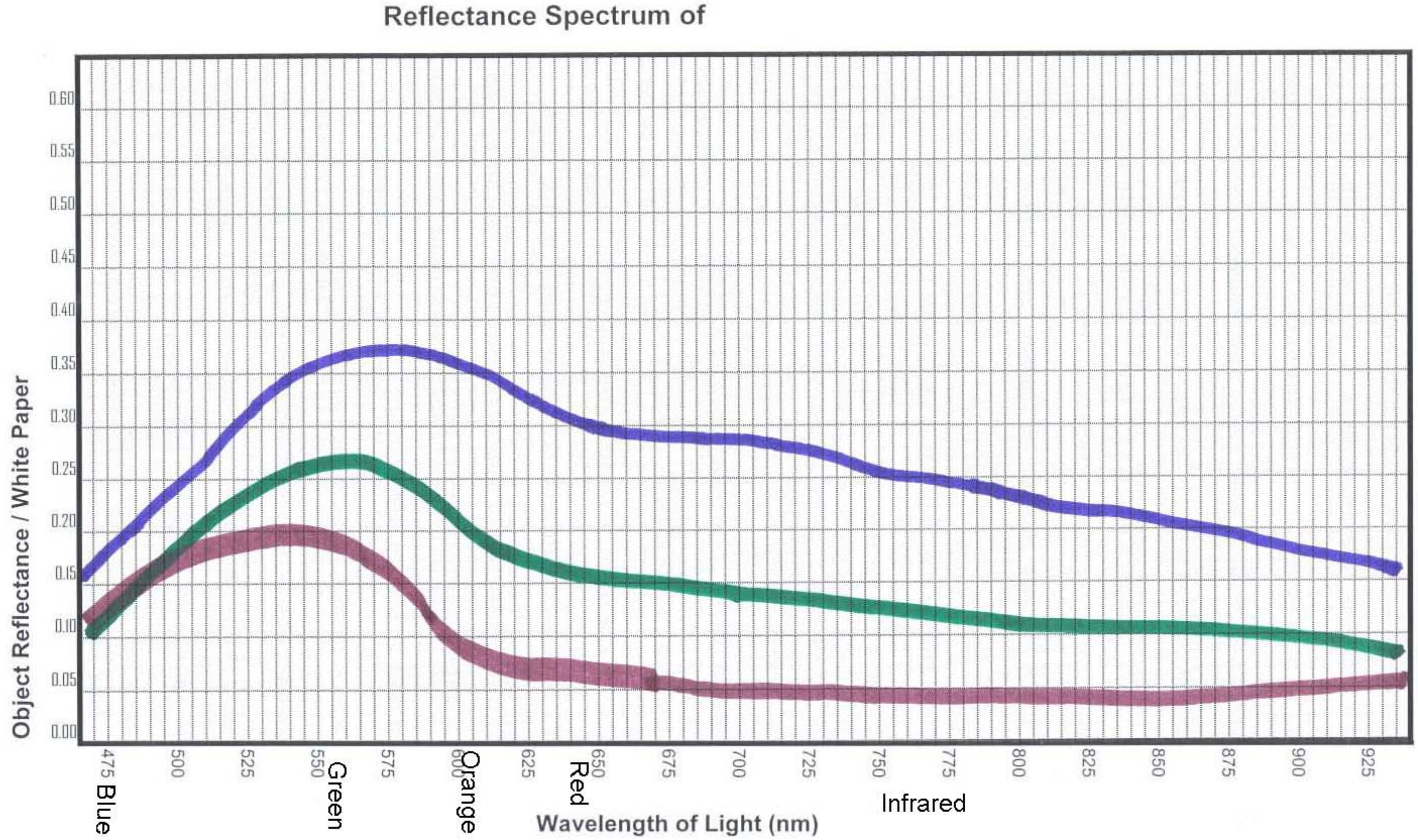
The pattern usually goes high for green (due to water-bearing earth minerals), then dips low for red. Remains low then slopes higher for infrared.



Basalt

Pattern remains fairly low with few ups and downs.



Dunite (Olivine) Pattern is low for blue, slopes higher for green and yellow, flows down for red. Slope continues down for infrared usually, unless sample is fairly dark.	

Rock Information Sheet

Rock Type: Rhyolite
Description: Rhyolite is a volcanic rock with few or no visible crystals. Rhyolite ranges in color from light grey to pink. It feels lighter than many other volcanic rocks. It may have layers that mimic sedimentary rocks. It has large amounts of the minerals quartz and potassium feldspar; it has varying amounts of plagioclase feldspar.

Locations on Earth: Rhyolite is found in continental crust, near explosive composite volcanos.

Formation: Rhyolite comes from lava formed by melting the Earth's crust, such as melted continental crust or a combination of melted ocean and continental crust. Rhyolite often forms when volcanic ash from an explosive eruption settles in layers.

Rock Type: Basalt
Description: Basalt is a dark grey volcanic rock with few or no visible crystals. It is heavier than most rocks. It has large amounts of the minerals plagioclase feldspar and pyroxene, and some olivine.

Locations on Earth: Basalt is found on the ocean floor and makes up the ocean crust. It is also found around shield volcanos like the Hawaiian Islands, and it can form huge, stacked sheets on land, such as the Deccan Traps in India and the Columbia River area of the United States.

Formation: Basalt is formed when magma from the Earth's mantle erupts onto the Earth's surface and cools quickly.

Rock Type: Limestone Chalk
Description: Limestone chalk is white sedimentary rock. It is lighter than the average rock on Earth. It has large amounts of calcite, also known as calcium carbonate, which fizzes when an acid, like vinegar, is dropped on it.

Locations on Earth: Chalk is found in rock deposits on land and in water.

Formation: Chalk is formed in deep seas and oceans from the shells or outer coatings of micro-organisms.

Rock Type: Dunite Olivine
Description: Dunite is a rock composed mostly of the mineral olivine, it is olive-green colored. Olivine is common in basalt lava rocks, and makes up most of the Earth's interior (its mantle). Olivine is usually light green but can also be colorless or greenish brown to black. It is heavier than the average rock, because it contains a large proportion of iron and magnesium.

Locations on Earth: Olivine is most commonly found in basalt lava rocks (like in Hawai'i), and in rocks where basalt lava cooled slowly underground. Olivine is very abundant in the rare places where bits of the Earth's mantle has been forced up to the Earth's surface.

Rock Type: Anorthosite

Description: Anorthosite rock is made mostly of large crystals of the mineral plagioclase. Its color varies from dark grey to white, and can be greenish. Anorthosite can contain small amounts of other minerals – mostly pyroxene and olivine.

Locations on Earth: Anorthosite is found where ancient mountains have been deeply eroded to expose what used to be many kilometers deep in the Earth. In North America, anorthosite is abundant in upstate New York, in Labrador, in southern Ontario, and in a few spots in southern California.

Formation: Anorthosite forms from basaltic magma inside the Earth's crust, but exactly how is not known.

Reflectance Worksheet

Names of Scientists on Team

______________________________ ______________________________

______________________________ ______________________________

Sample Description ______________________________

____

____

____

Dark Voltage Constant ______________________________

Color	Wavelength in Nanno-meters	White Paper Reading	Dark Voltage Constant	White Paper Reading - Dark Voltage (A)		Sample Reading	Dark Voltage Constant	Sample Reading -Dark Voltage (B)		B / A or (Sample – Dark V) / (White – Dark V)
Blue	470									
Cyan	525									
Green	560									
Yellow	585									
Orange	600									
Red	645									
Deep Red	700									
Infrared 1	735									
Infrared 2	810									
Infrared 3	880									
Infrared 4	940									

Module 3

In this module, students will continue their exploration of the properties of the Moon and will create their own hypotheses on the Moon's geological history, and the role that the Moon Mineralogy Mapper will play in testing scientists' current understanding of the Moon's composition and geologic history.

*The role of impact cratering and of volcanic eruptions and lava layering on the Moon are critical to the Moon's geologic history. We strongly recommend that before conducting Activity A, classes participate in modeling of cratering and of volcanoes, from the modified activities present in the **Geology** section of the Moon Mineralogy Mapper Education Web site.*

Activity A: Lunar Treasure Hunt (40 minutes)
Teams compare their maps to topographic maps of the Moon. Students use their spectroscopic data from the Moon and understanding of cratering to create questions and devise some theories for the geologic history of the Moon. What do students feel is the value of spectroscopic data? What questions do they have about the Moon? How can the Moon Mineralogy Mapper help resolve some of the questions?

Activity A: Lunar Treasure Hunt

Overview

In this 40 minute activity, teams of students create and compare color-coded mineralogy maps and topographical maps of the Moon. Using spectroscopic data and their understanding of cratering and volcanism, students create questions and devise theories for the geologic history of the Moon.

Learning Objectives:

The student will be able to

- Contrast mineralogy maps and topographical maps of the Moon to describe lunar features in terms of their rock types.
- Evaluate the value of spectroscopic data.
- Create and examine hypotheses explaining the geologic history of the Moon.

Key Concepts:

- The Moon has small craters that reflect light well at some wavelengths (visible and mid-infrared) so they appear bright.
- The Moon has large round basins that reflect light poorly at many wavelengths (from ultraviolet through infrared) so they appear dark.
- Craters provide clues to the composition and internal structure of the Moon.
- Our understanding of the Moon is based on the Apollo rock samples and meteorites from the Moon, and our spectroscopic and visual observations of the Moon.
- More detailed data are needed to test our current models of the Moon's rock types, geologic history, and structure.
- Scientific investigation includes observations, gathering, analyzing, and interpreting data, and using technology to gather data.

Materials

For each group of 4-5 students:

- Results of the Remote Analysis of the Moon (Module 2)—the identities of the spectra of Rock Type #1, Rock Type #2, and Rock Type #3 (anorthosite, basalt, and dunite (olivine), respectively)
- A color copy of the *Lunar Topographic Map*
- A regular copy of *Color Coded Moon Map* with regions characterized by numbers
- Colored Markers or crayons: yellow, grey, and green
- A copy of each of the Rock Sample Information sheets

Preparation:

The role of impact cratering and of volcanic eruptions and lava layering on the Moon are critical to the Moon's geologic history. We strongly recommend that before conducting

*Activity B, classes participate in modeling of cratering and of volcanoes, from the modified activities present in the **Geology** section of the Moon Mineralogy Mapper Education Web site.*

Print out color copies of the *Lunar Topographic Map* for groups of 4-6 students, or print out posters for the entire class to observe, or prepare to project the image for everyone to see.

The Activity

1. Begin by asking the class to describe their previous activities related to the Moon, particularly the *Remote Analysis of the Moon*, their examination of missions gathering data from the Moon, and the geology activities on cratering and lava layering.

   How have these activities helped you to understand the Moon? [Students have gathered data about the types of rocks on the Moon, they have examined data taken by spacecraft of the Moon, and they have experimented with models of cratering and volcanic activity.]

   What types of rocks have scientists found on the Moon? [anorthosite, basalt, dunite (olivine-rich), and more]

   Why do we think those are the rocks on the Moon? [We have samples of these rocks gathered by the Apollo astronauts from a few specific locations on the Moon, and we have spectroscopic data for larger areas on the Moon.]

   What rock samples did the students analyze that occurred on Earth but not the Moon? What might this tell you?

   Could there be other types of rocks on the Moon? How complete is our knowledge? [There could be other types of rocks; our data is patchy and low-resolution.]

   What do we need to have a more thorough understanding of the Moon? [We need a more detailed data for the entire surface of the Moon.]

2. Ask your students if their activities have led them to questions about the Moon and its features. Tell them that they will be forming hypotheses about the Moon, and evaluating those hypotheses.

3. Divide your class into groups of 4-6 students. Give each group a copy of the *Color-Coded Map* of the Moon, along with either crayons or markers. Invite the students to create a map of the composition of the Moon's surface—a mineralogical map of the Moon. The numbers on the map indicate where spectra have been taken, matching the rock types the "Orbiters" collected. For instance, wherever a "2" is shown, a

spectrum was collected from rock type 2. Using their information from *Remote Analysis of the Moon,* students should identify the rock types and color in the map.

Is there any pattern to the distribution of rock types? Which cover the greatest area? The least?

4. After they are finished color-coding their maps, review what they know about the rocks and how they form from module 2. The students may need to revisit the *Rock Information Sheet*. Ask them to reflect on where the different rock types occur on their mineralogical map of the Moon.

   How do basalts form? [Basalts are volcanic rocks that form from molten lava.]

   What does the presence of basalt on the Moon tell them? [That the Moon was or is volcanically active.]

   Do they see any patterns to where the basalts occur on their map?

   What other ideas or questions do your students have so far, based on this information?

5. Hand out a copy of the *Lunar Topographic Map* to each team. Students should identify key features from the *Lunar Topography* map.

   Which parts of the Moon are the highest (the highlands)? Which parts of the Moon are the lowest?

   How would the students describe the lowlands? [Smooth, dark.]

   How would the students describe the highlands? [Light, rough.]

   What makes the highlands rough? What are the circular depressions called? How do they form? [Remind the students that they experimented with forming craters in the _______ activity.]

   Which of the craters are the deepest?

   What are some of the properties of the basins? [Basins are broad flat low features.]

   Are some of the basins higher than others?

   Which of the basins have the most craters in them? Which of them have the fewest craters? What does that tell us about the ages of the basins? [The basins with more craters are older; the basins with fewer craters are younger.]

6. Teams compare their mineralogy maps to topographical maps of the Moon, and classify the rocks in the craters, in the basins, and in the highlands.

   What types of rock is found in the basins? [basalt] *Are these basins different from each other?*

   What types of rocks are sometimes found inside the craters? [anorthosites, dunite(olivine), and others] *Are these craters different from each other?*

   What types of rocks are found in the lunar highlands? [mostly anorthosite] *Are these regions different from each other?*

7. Ask your students to think about the Moon, its topography, the types of rocks found in different locations on the Moon, and where those rocks are found on Earth.

   Which parts of the Moon are the oldest? Why do they think so? [the highlands are the oldest; they have the most craters]

   What types of rocks are found in the oldest parts of the Moon? [anorthosite]

   Which parts of the Moon are the youngest? Why do they think so? [The flat basalt-filled basins are the youngest; they have the fewest craters.] *Where are those rocks found on Earth? How do you think they formed there on the surface of the Moon?* [Scientists believe that cracks in the Moon's crust allowed hot lava from inside to flow out onto the Moon's surface.]

   Which parts of the Moon's surface are the deepest? [craters] *What types of rocks are found there?* [anorthosites, dunite (olivine), and others] *Where are those rocks found on Earth?* [dunite is found in our mantle] *How do you think they got to the surface of the Moon?* [Impacts uncovered the layers above these rocks, exposing rocks that may have intruded into the crust of the Moon.]

8. Ask your students to create a hypothesis on the history of the Moon, and to work in groups to write their hypotheses. This can be in the form of a very short paper, a powerpoint presentation, or even an illustrated design with written descriptions.

   How has the Moon's surface changed throughout its history? What happened first? What came next? What has happened most recently to change the Moon's appearance?

9. Ask the groups to describe ways they could test their hypotheses.

   What type of data could support or disprove their hypotheses? [Dates for samples of the rocks from different parts of the Moon, a map of the rocks over the entire surface of the Moon, drilling to show deeper layers inside the Moon]

Are any of the planned missions going to gather data that could help test their hypotheses? [The spectroscopic data from the Moon Mineralogy Mapper will help scientists learn more.]

10. Each group should have 5 minutes to present their hypothesis to the class. After all of the presentations, invite the students to compare the different hypotheses in an open discussion.

11. Ask your students to go back to their groups, and to pick the spot on the Moon that they would select to test their hypothesis. Invite them to mark this position on their Color-Coded Mineralogical Map of the Moon, and to write a paragraph on why they would select that spot, based on everything they have learned about the Moon.

12. Invite the students to reflect on the activity and analyze their understanding of our exploration of the Moon.

    What do the students think the point of this activity was? [Answers could include analyzing data, creating hypotheses, understanding the scientific process, and understanding the formation and evolution of the Moon.]

    Which aspects of science did your students do today? [Answers could include analyzing or comparing data, creating hypotheses and making predictions, sharing conclusions.]

    What do your students believe is the value of understanding what our Moon is made of? [Knowing about resources for future manned exploration of the Moon; compositional information can be used to improve our current models of the Moon's formation and its geologic evolution.]

    What do your students believe is the value of understanding the Moon's formation or evolution or structure? [Scientists can apply what has happened to our Moon to better understand our own Earth and the broader history of the Solar System.]

Background

Features on the Moon

The Moon has many features visible from Earth. We can easily see brighter areas and darker regions. Through telescopes, the dark regions appear smooth, while the bright areas are more rough. Each feature reveals a piece of the Moon's geologic history.

The brighter surface of the Moon in general is high and rough, and is called the "lunar highlands." This is believed to be largely composed of the mineral anorthite, which makes up the rocks anorthosite.

The large round dark areas that are obvious in photos of the Moon are called “basins” or “seas.” They have relatively smooth dark surfaces and are low or even deep in the Moon’s crust. The basins were formed by enormous impacts around 3.8 billion years ago. Much later, the enormous holes were filled with basalt, which flooded these portions of the Moon between 3.1 billion and 3.8 billion years ago. At the same time, some lava exploded like a fountain onto the surface, cooling to become volcanic glass. The Moon has been geologically inactive – except for cratering processes and some degassing – for the last billion years.

The Moon is also covered with craters. Craters are smaller than basins, with sharp rims. They can have long bright rays, formed when rocks from the impacts sprayed out in all directions. They also may have a central peak, and rocks that were either splashed out or exploded out called ejecta. Craters are typically bright in most photos, at most wavelengths. The brighter the crater, the more recently it was formed. Some craters have spectral signatures of some olivine, perhaps blasted out from the bottom of the crater during the impact explosion.

The Moon is also covered with breccias, formed over millions of years as rocks have been tossed about and on top of one another from impact after impact. Breccias are very rough angular rocks made of many smaller broken rocks cemented together by cooled lava. Because a breccia is composed of many different types of rock pieced together, it has no flat surfaces and its reflectance spectrum is different from different angles.

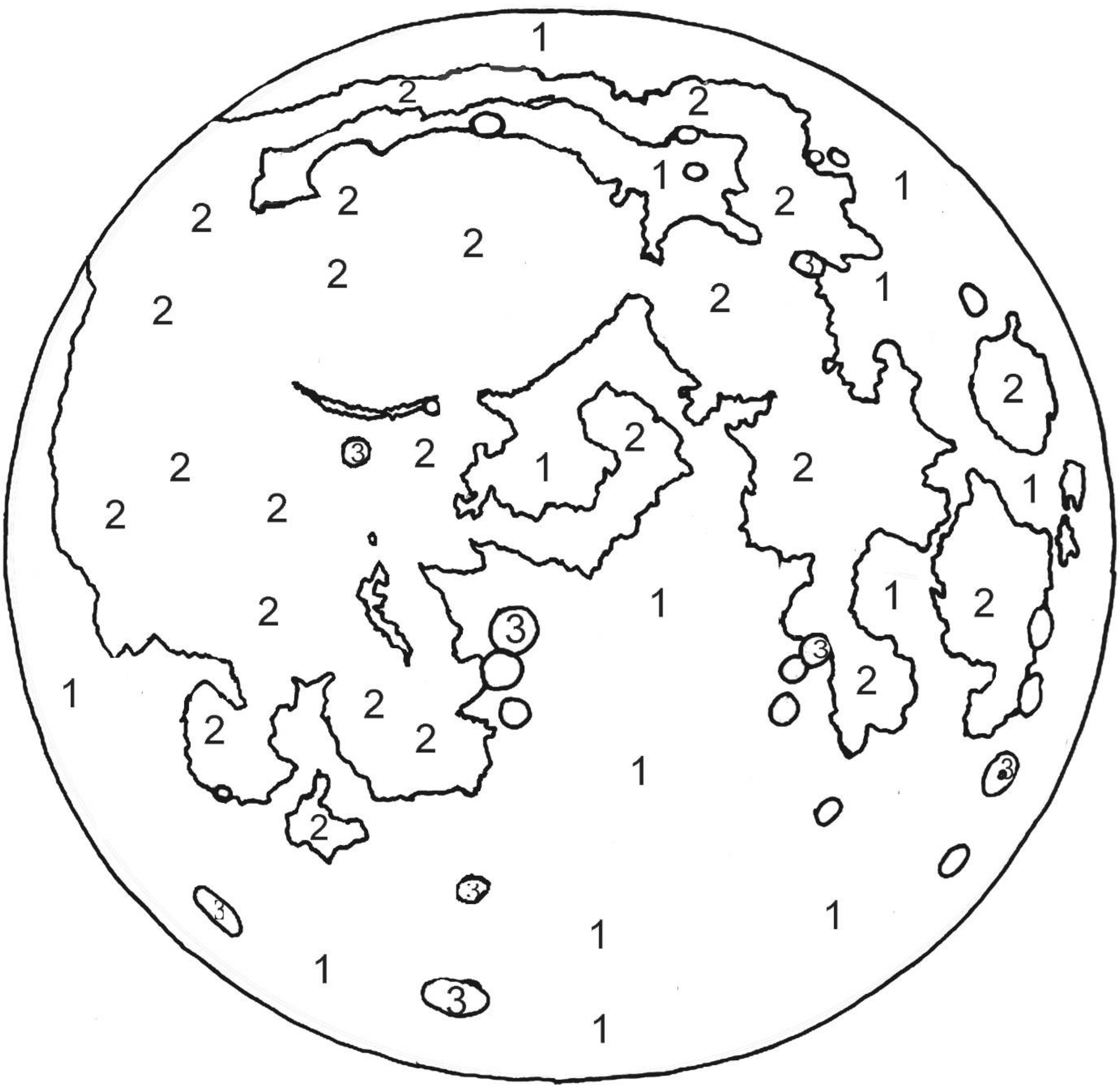
The Moon has no large volcanos; small ones are visible in close high-resolution photos), no water, no visible ice caps, no atmosphere (and therefore no weather).

Color-Coded Moon Map

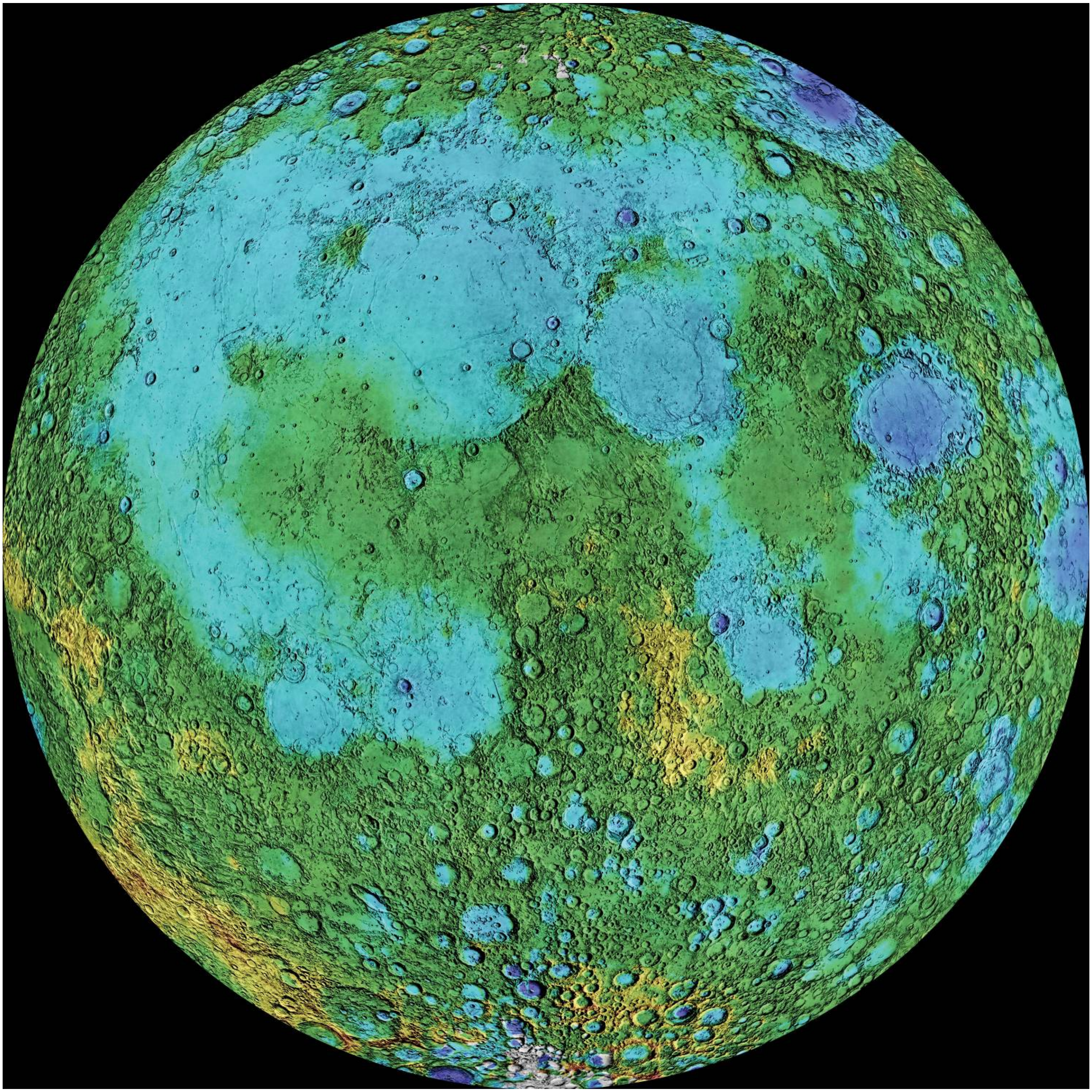
Directions: color the areas with the anorthosite spectrum yellow, color the regions matching the basalt spectrum dark grey, and color the portions matching the olivine spectrum green.

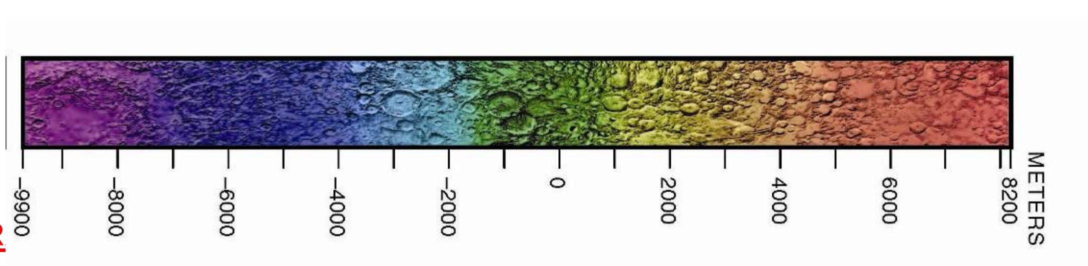
Code:

1 is
2 is
3 is



Topographical Map of the Moon





Appendix:

References Cited

Web Sites for Further Exploration

Resources about student misconceptions of light and the electromagnetic spectrum

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2. Watts, D.M. 1985. Students' conceptions of light-a case study. *Physics Education* 20: 183-187

3. Zylbersztajn, A. and Watts, D.m. (1982) *Throwing Some Light on Colour* Mimeograph, University of Surrey

4. Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science: Research into children's ideas.* London and New York: RoutledgeFalmer.

5. Anderson, C. and Smith E. (1986) Children's Conceptions of Light and Color: Understanding the Role of Unseen Rays. Research Series No. 166.

6. Eaton, J., Harding, T., and Anderson, C.W. (1985) *Light: A teaching module*. East Lansing, MI: Institute for Research on Teaching, Michigan State University.

7. Plait, P. (2007). http://www.badastronomy.com/bad/misc/apollohoax.html

8. The "Minds of Our Own" DVD: http://www.learner.org/resources/series26.html

Web Sites for Further Exploration

Moon Mineralogy Mapper Education Web site
NEED THE FULL WEB SITE
A suite of hands-on inquiry based activities engage middle-school students in understanding and interpreting reflectance spectra from Earth and Moon rocks. These activities are part of a suite of educational resources that investigate the geologic history of our Moon, the Chandrayaan-1 Mission, spectrometry, and future lunar exploration.

The Electromagnetic Spectrum
http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html
Imagine the Universe investigates the spectrum and offers lesson plans for exploring emission spectra from supernovas for grades 9-12.

Cool Cosmos
http://coolcosmos.ipac.caltech.edu/
What does a cat look like in the infrared? Tour Yellowstone in the infrared and learn more about this portion of the electromagnetic spectrum through discussion, activities, images, and games at this rich site.

Northwestern University Reflectance Spectroscopy Lab
http://ser.sese.asu.edu/SPECTRA/
Explore reflectance spectroscopy and perform online analysis of lunar and Martian rocks in this undergraduate laboratory exercise.

Active Astronomy
http://www.sofia.usra.edu/Edu/materials/activeAstronomy/activeAstronomy.html
Infrared activities (geared for 7th grade through high school)

ALTA II Reflectance Spectrometer for the Classroom
http://www.vernier.com/labequipment/altaspectrometer.html
The ALTA is a rugged, simple classroom instrument designed to help students in grades 5 to undergraduate learn about light, color, and spectroscopy. Using the spectrometer, students can collect spectral data on the proportions of colored light (including infrared) that reflect from real-world objects. Lesson plans are included.

Rock Around the World
http://ratw.asu.edu/
Send a rock for spectral analysis! Scientists studying Mars are collecting spectra from Earth rocks so that they can compare the spectral data collected by Martian spacecraft.

Mars Student Imaging Project
http://msip.asu.edu/index.html

Students in grades 5-12 analyze THEMIS visible spectrum camera aboard NASA's Mars Odyssey spacecraft.

Missions

The **Moon Mineralogy Mapper** (http://moonmineralogymapper.jpl.nasa.gov/) is one of NASA's instruments aboard the Indian Space Research Organization's Chandryaan spacecraft (http://www.chandrayaan-1.com/index.htm). It will map the entire lunar surface, and reveal the minerals of which it is made. Extensive educator content and classroom resources are available on the education pages.

NASA's **Lunar Reconnaissance Orbiter** mission (http://lunar.gsfc.nasa.gov/) will return detailed information about the surface of the Moon and the lunar environment. Explore the Outreach pages for links to more activities and resources.

The Japan Aerospace Exploration Agency's **SELENE** mission (http://www.jaxa.jp/projects/sat/selene/index_e.html) will gather gravity, magnetic, and compositional data from the Moon to help scientists better understand how the Moon formed and has changed through time and to support future exploration.

European Space Agency's **SMART-1** spacecraft (http://www.esa.int/SPECIALS/SMART-1/index.html) orbited the Moon for three years, collecting spectra to characterize the composition of the lunar surface and provide chemical data that would help scientists understand how our Moon formed.

The **Clementine Mission** (http://nssdc.gsfc.nasa.gov/planetary/clementine.html) was a joint venture between the Department of Defense and NASA to test instruments in long-term space environment and to acquire a global multispectral map of the Moon's surface.

NASA's **Lunar Prospector** (http://lunar.arc.nasa.gov/) spacecraft orbited the Moon, acquiring a global map of lunar resources, gravity, and magnetic fields. The education section offers a teachers guide, lesson plans and a multitude of other resources.

NASA's **Galileo Mission** (http://galileo.jpl.nasa.gov/gallery/earthmoon.cfm) made two passes by the Moon, providing the first multispectral images