

Lesson Summary

Students will use a reflectometer to determine which minerals are present (from a set of knowns) in a sample of Mars soil simulant.

Prior Knowledge & Skills

- Activities “Patterns and Fingerprints,” “Graphing the Rainbow” and either “Using Spectral Data to Explore Saturn and Titan” or “Goldilocks and the Three Planets”
- Experience interpreting data
- Graphing skills

AAAS Science Benchmarks

The Nature of Science

The Scientific Worldview (middle school)

Scientific Inquiry (middle school)

The Nature of Mathematics

Patterns and Relationships (high school)

The Nature of Technology

Technology and Science (middle school)

The Physical Setting

The Structure of Matter 4D/M9 (middle school)

Energy Transformations (high school)

The Mathematical World

Symbolic Relationships (middle and high school)

Shapes (middle school)

Habits of Mind

Communication Skills (middle school)

Computation and Estimation 12B/H2 (high school)

Manipulation and Observation (high school)

NSES Science Standards

Science as Inquiry

Abilities necessary to do scientific inquiry (middle and high school)

Physical Science

Interactions of energy and matter (high school)

Science and Technology

Understandings about science and technology (middle and high school)

NCTM Mathematics Standards

Data Analysis and Probability: *Formulate questions that can be addressed with data, and collect, organize, and display relevant data to answer them (middle and high school); Develop and evaluate inferences and predictions that are based on data (middle school)*

Colorado State Standards

- Science: 1 (Physical Science)
- Math: 3 (Data Analysis, Statistics, and Probability)

Teaching Time: 60 minutes

Materials

Each group of 4-5 needs:

- 6 sheets of paper
- 1 sheet of transparency paper
- 1 ALTA II reflectance spectrometer
- 1 facemask per student

To Share with Class:

- 5 ALTA II spectrometers
- 5 small boxes (ideally about 9 cm long x 7 cm wide x 3 cm high)

To Build:

- Scrap cardboard or foam core board
- Black construction paper
- Utility knife or X-ACTO knife
- Packaging tape
- Glue sticks
- Wet-erase, fine-tip markers
- N95 respirator masks
- Mars soil simulant
- Silicon dioxide
- Calcium sulfate
- Ferric oxide
- Cupric sulfate

Advanced Planning

1. Acquire ALTA II spectrometers (if borrowing from the Lunar and Planetary Institute, written request must be provided 6 weeks in advance).
2. Acquire mineral samples; allow at least two weeks for shipping.
3. Familiarize the class with the ALTA II.

Preparation Time: 30-60 minutes

1. Gather or construct small boxes
2. Carefully place mineral samples in boxes
3. Gather materials
4. Set up 5 work stations

Why Do We Care?

Scientists and engineers use reflectometry to determine the composition of surfaces and combine this information with data from other instruments to verify these measurements. This is how we know what makes up a planet. We could use this knowledge to establish a history for the planet and how the Solar System evolved. Is it currently, or has it ever been habitable? Does it have resources we could use on Earth or if we traveled there? Could humans live there?



Marvelous Martian Mineralogy

Expendable Cost per Group \$5

Engineering Connection

Engineers create tools such as the reflectometer. A reflectometer uses something called a photometer to collect and measure light. Spacecraft often use photometers to collect reflected sunlight from a surface or atmosphere. On the Mars Express orbiter an instrument called the OMEGA: IR Mineralogical Mapping Spectrometer uses a photometer to take very detailed reflectance spectra of the Martian surface to determine what minerals exist on Mars.

Learning Objectives

After this activity, students should be able to:

- Describe, in basic terms, how a reflectometer works
- Demonstrate how reflection can be used to determine the mineralogy of a planet or other surface
- Describe the mineralogy of the Martian sample

Notes on materials:

ALTA IIs can be purchased from Vernier for \$165 each. <http://www.vernier.com>

They may also be *loaned* for the cost of shipping from the Lunar and Planetary Institute (LPI).

Written request must be provided six weeks prior to doing ALTA lessons. Twenty ALTA IIs will be delivered to your classroom. <http://www.lpi.usra.edu/education/products/spectrometer/>

N95 respirator masks should be purchased per student if a hood is not available for the ferric oxide. These masks may be purchased at any hardware store, and often come in multipacks of 10-30.

Typically, these will be between \$8-\$20/pack. Inexpensive (\$4 and up) disposable respirator N95 masks may be purchased in packs of 20-30 at: <http://www.grainger.com>.

To find the items quickly, in the search window type “disposable respirator N95 mask,” sort by price on the top bar, and also click “Clearance Items” under “Shop Items By” in the left bar. The cheapest masks may not come up automatically.

Orbitec

<http://orbitec.com/store/>

2 lbs Mars Soil Simulant \$20.00

Spectrum Chemical

www.spectrumchemical.com

500 g of:

Silicon Dioxide \$31.35

Calcium Sulfate \$28.75

Prices are from 2009. *All chemicals can be used indefinitely unless cross-contamination occurs.*

Carolina Biological Supply Company

www.carolina.com

500 g of:

Ferric Oxide \$12.85

Cupric Sulfate \$9.50

Introduction / Motivation

If it looks like a duck, and quacks like a duck, it's probably a duck. We use our senses to establish different things about our environment. For example, you have a clear, colorless, and odorless liquid, you can use your senses to figure out that it's probably water. Your eyes can give you a whole lot of information just on their own too. Based upon the knowledge you already have, you can simply look at an object and identify it. "Wow," you say, "That sure looks like a duck!" From there, you can look at the color and features of the duck to figure out the species and gender.

Today we'll be exploring Martian soil (*pour some of the soil on a piece of paper or in a container for students to observe*). You've learned how a spectrum can be taken of an atmosphere. Well, the spectrum can also be taken of the surface of a planet or other object. Sometimes, astronomers take what is called a "reflectance spectrum" of a surface. Similarly to how you identified that duck, we can look at the reflected spectrum of the material and figure out its composition. When light, usually from the Sun, hits the surface of a planet or object, some of it is absorbed, some is reflected, and some may even transmit through the surface. When light reflects off of the surface, we can take the reflected spectrum and compare it to the reflectance spectrum of materials measured in a lab. Since we make measurements of materials in the lab, it is fairly easy to determine what minerals exist on the surface of other planets or solar system bodies. It is not as accurate as the methods you saw in other lessons because you won't necessarily get nice sharp dips and peaks in your spectrum because you are looking at a reflection from a solid surface rather than emission from a gas.

You and your team will explore different chemicals that can exist in a Martian soil sample. Your goal will be to figure out what makes up the dirt from an imaginary return sample from Mars. You will also have to figure out how we know what kinds of ice are on the Martian surface.

Vocabulary / Definitions

Spectrograph (also Spectroscope)	A tool that breaks light into its components
Reflection	When a wave (in this case, light wave) reaches a surface and changes direction
Reflectometer	A meter that measures the reflection off a surface
Light Source	Any object that produces light

Procedure Background

Spacecraft often use passive systems. One passive system, called a photometer, collects light from the Sun that reflects off of the surface or atmosphere of a body. The particular reflectometer, the ALTA II, used in this lab produces its own light, so it is an active system. It has a photometer and different lights that shine at specific wavelengths ranging from blue to infrared. When the lights are turned on, the photometer measures the light that reflects off of the surface.

ALTA II Wavelengths

Portion of electromagnetic spectrum	Wavelength (nanometers, nm)
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

Students will need to take a dark voltage reading before every sample measurement. A dark voltage reading is what the ALTA II reads when no lights are illuminated and it is pressed flat against a surface. Each ALTA II will have a slightly different reading, and the reading may change over time due to temperature variations. Dark voltage is instrument *noise* created within the photometer, which will need to be subtracted from the measurements.

To calibrate the ALTA II, students will need to measure the amount of light reflected by a bright surface and compare that measurement to their sample measurement. To do this, students must place the ALTA II on 4 stacked sheets of white paper, press each button one at a time and record the values in the table provided in the lesson for each of the 11 wavelengths.

As stated previously, students need to subtract the dark voltage measurement from the white paper and sample measurements because it is instrument noise. Students will then compute the percent reflectivity. If we consider that the white paper yields the maximum amount of reflectivity for each LED, each sample measurement will be a percentage of the maximum reflectivity. The percent reflectivity will be different for each wavelength. For example, a reddish material might only be ten percent (10%) as reflective at a blue wavelength as the white paper since redder materials absorb blue and reflect red. Perhaps that same material is sixty percent (60%) as reflective as the white paper at a red wavelength. Below are the equations for the lab:

White paper - dark voltage = A

Sample - dark voltage = B

% Reflectivity = R

$$R = (B/A) \times 100$$

$$\% \text{ Reflectivity} = \frac{\text{Sample} - \text{Dark voltage}}{\text{White reading} - \text{Dark voltage}} \times 100$$

Mawrth Vallis is where the soil sample has come from in the imaginary mission presented in this lab. It is a real site on Mars, which is on the short list of potential landing sites for the Mars Science Laboratory rover “Curiosity” that is expected to launch in 2011. Mawrth Vallis shows a wide variety of scientifically interesting terrain, as well as some potential hazards for landing. Scientists find this region interesting, in part, because the soil contains clay minerals that formed by chemical alteration of rocks by water, which indicates that water was flowing on the surface. Scientists are interested in water on Mars because they wonder if Mars was once habitable to life.

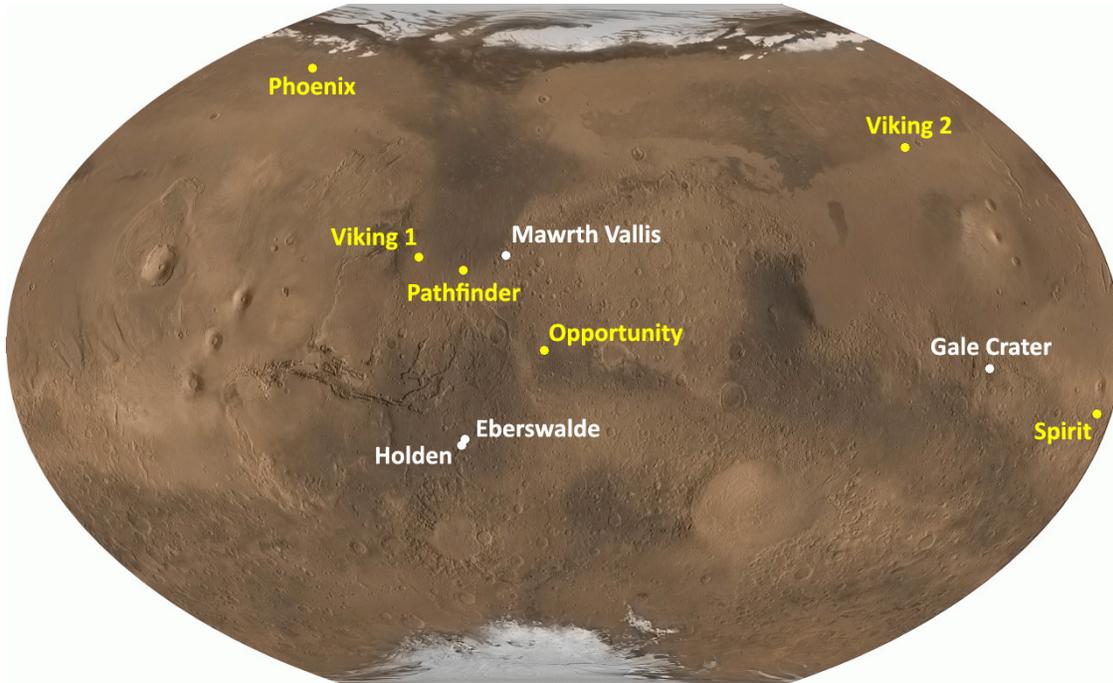
Before the Activity

- Make small boxes for each of the 5 stations. Print out Image 3 to create boxes and cut the paper along the solid lines. Place the cutout on a piece of cardboard or foam core board. Trace around the edges with a black pen, and draw the interior square using a straight edge (where dotted lines appear in cutout). Cut the board around the edges of the box first. Next, carefully cut (about half-way) into the cardboard or foam core board along the interior square using a utility knife or X-ACTO knife without cutting through the opposite side of the board. Fold the sides up and tape the box inside and out so that there are no open seams. Line the box with black construction paper and glue down with a glue stick. The boxes need not be perfect.
- Fill each box with a different material about 1 cm from the top of the box. Label each box as it is filled since some materials look very similar. Place the boxes around the room in stations.
- Label the stations 1-5 with the material’s name
- Place 4 stacked sheets of white paper at each station
- Make copies of student handout for each student
- Make 4 copies of the “Student Graph Paper” for each group or provide 4 sheets of blank graph paper per group
- Print “Student Graph Paper” onto transparency paper, and provide one to each group OR provide transparency graph paper to each group (making sure the square size is the same for both paper and transparency versions)
- Hand out one ALTA II to each group
- Turn out all lights and shut blinds

With the Students

1. Explain safety procedures to students (see “Safety Issues”)
2. Break students into 5 groups.
3. Ideally, each student will have a “job.” Students should switch jobs between stations. One student should instruct the group on the procedure, one should use the ALTA II and read out the measurements, one student should be recorder of the measurements, and one student should be in charge of recording the description of the material. If too many students are in a group, it is possible that one or more students will be jobless at a given station. These students may begin calculations and graphing while the other students are making measurements or may also record data.
4. Send each group of students to one of the stations
5. Instruct groups to rotate through each station

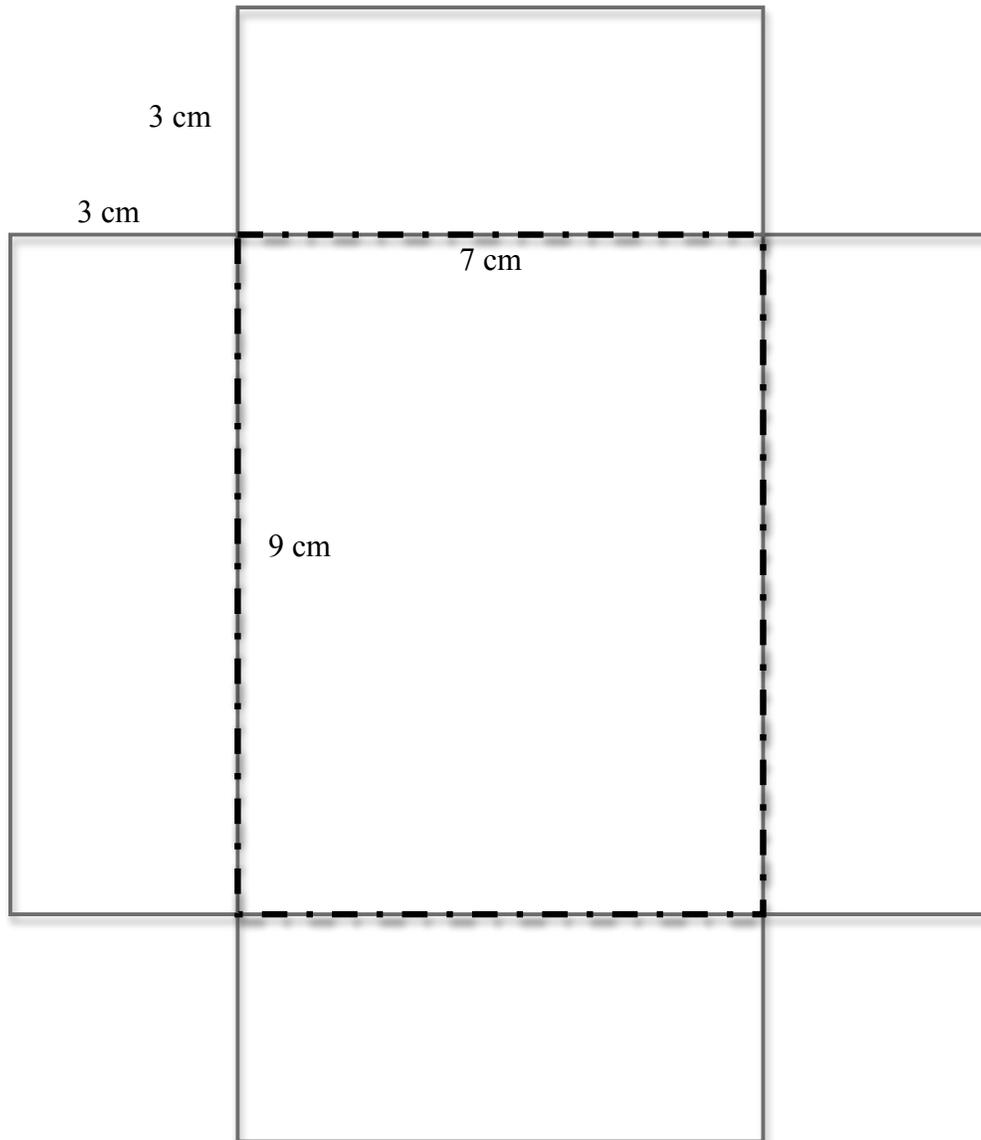
Image 1



With a lot at stake, two sides of the Mars team--scientists and engineers--have been lobbying for the best candidate landing site for the Mars Science Laboratory rover. Scientists have been pouring over data from Mars orbiters. They have searched for sites that are most likely to help us understand Mars' ability to support life in the past. In the above image, potential landing sites of the rover "Curiosity" are represented by white dots. The landing sites of past missions, are represented by yellow dots.

Source/Rights: Image and caption text courtesy of NASA/JPL

Image 3: Building a Box



Make small boxes for each of the 5 stations. Print out image 3 to create boxes and cut the paper along the solid lines. Place the cutout upon a piece of cardboard or foam core board. Trace around the edges with a black pen, and draw the interior square using a straight edge (where dotted lines appear in cutout). Cut the board around the edges of the box first. Next, carefully cut (about half-way) into the cardboard or foam core board along the interior square using a utility knife or X-acto knife without cutting through the opposite side of the board. Fold the sides up and tape the box inside and out so that there are no open seams.

Safety Issues

- This lab uses chemicals that may be harmful if handled, inhaled, or ingested. Please observe standard laboratory procedure for the materials as outlined on the containers. It is necessary for students to wear rubber gloves, lab coats or smocks, and goggles.
- Ferric oxide is a respiratory irritant. The effects of contamination are not severe and are generally due to long-term exposure. Although the likelihood of severe contamination is small, airborne particulates could be harmful if the box is dropped or mishandled. N95 respirator masks are recommended for use with the ferric oxide if a hood is not available. While the ferric oxide is out, it is recommended that all students (and teacher) wear a mask. After making measurements of ferric oxide, if it is covered, a mask is not needed. The sample could be placed in a plastic container with a lid, for example. Students may use the same mask over again if the lab takes more than one day.
- Due to potential transfer of illness, it is not recommended that students share masks. After the lab is complete, masks should be thrown away.

Troubleshooting Tips

- The ALTA II should rest on the rim of the box, not directly on the soil or chemical.
- Make sure all of the ALTA II lights operate properly. Often, a low battery may prevent all lights from lighting up. The visible lights will appear to light if the battery is full, but most of the infrared lights are not visible to the naked eye. Test the infrared lights against a white piece of paper before the lab. The readings on the display should be higher than the dark reading.
- The ALTA II lights should only be turned on one at a time.
- Each ALTA II has its own unique sensitivity to different wavelengths of light due to variations in electrical components, lamps, and light sensors. Readings can change over time, due to temperature and other variables.
- The ALTA II should be pressed firmly over the sample box. The dark voltage (the reading without any of the LEDs turned on) should be within five numbers of the dark voltage the students recorded when the ALTA II was pressed against a flat surface. If it is not, outside light is getting in, and they should reposition the ALTA II until the numbers are close to the recorded dark voltage before making measurements.
- Some of the buttons on the ALTA II are difficult to press. If students' data seem unusual ask them to try again. If students have difficulty pressing or holding buttons down, have them use a pencil eraser to push the buttons.
- Because every ALTA II is a little different, and the same ALTA II may even vary between measurements, it is very likely that every group's plots will be slightly different. The important aspect is that the shape of the plots should be about the same between groups. When students look for the correct constituents of the soil, they should be carefully looking at the peaks and dips in the plot, not that the plots are a perfect match. Please see the Teacher Solution for details.
- Shake the Mars soil simulant before pouring. The ferric oxide tends to collect at the bottom.
- Non-corrective, vision-impaired students will have difficulty with portions of this lab.



Marvelous Martian Mineralogy

References

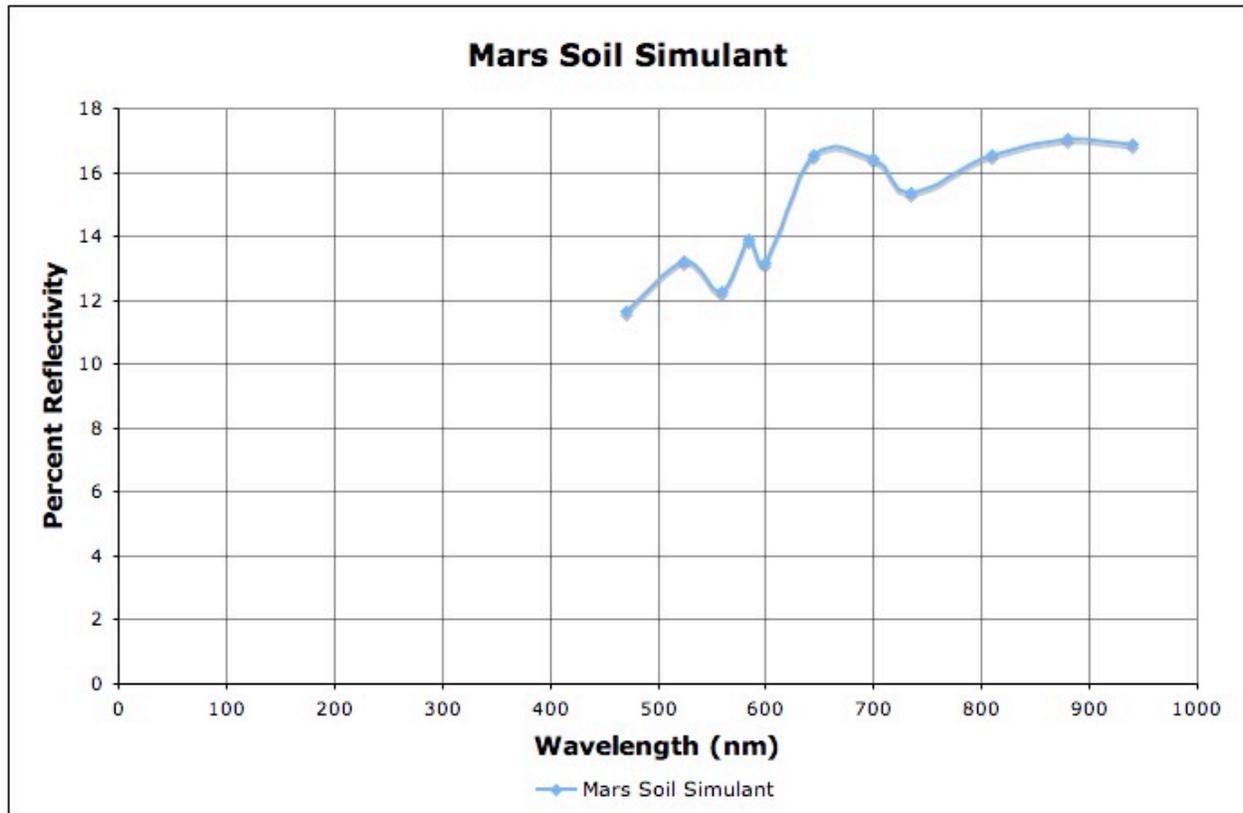
Cas Runyan's Seeing the Moon: Using Light to Investigate the Moon, A Series of Inquiry Activities Created for Chandrayaan-1's Moon Mineralogy Mapper Instrument

Owner

Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder

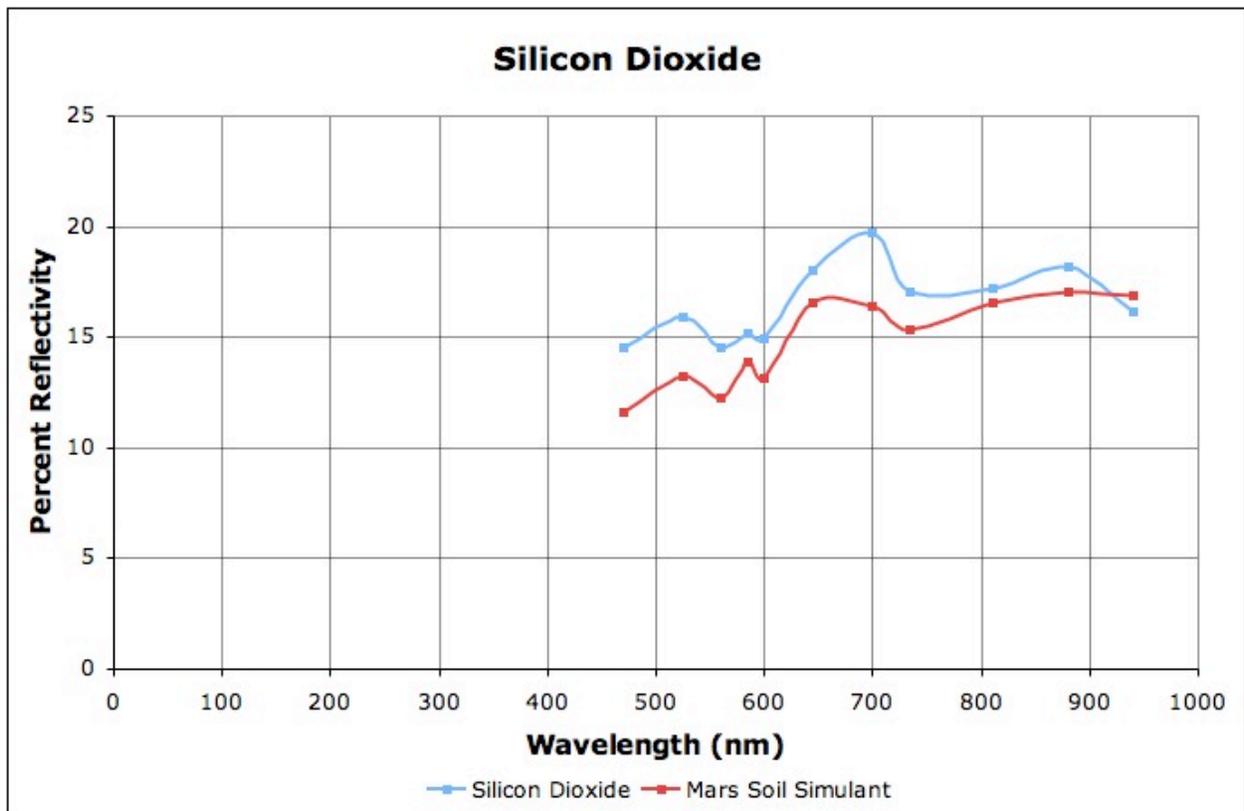
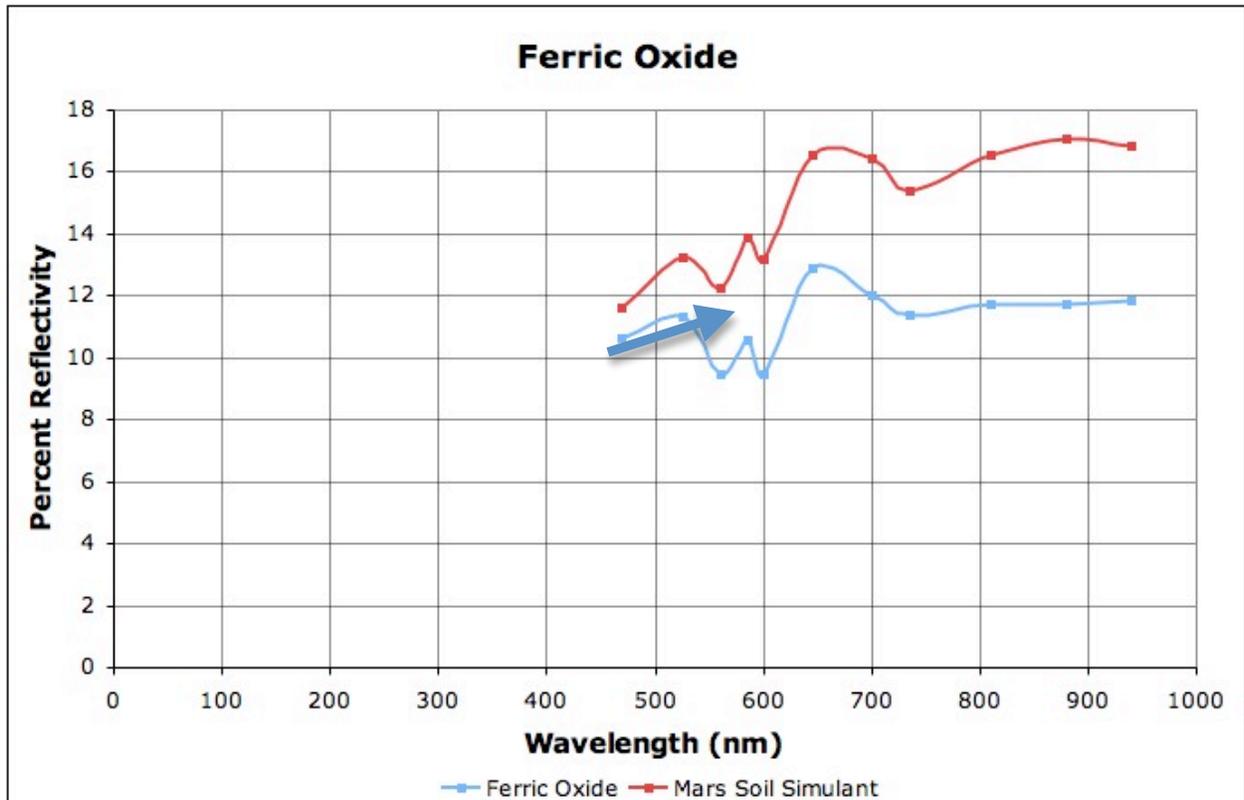
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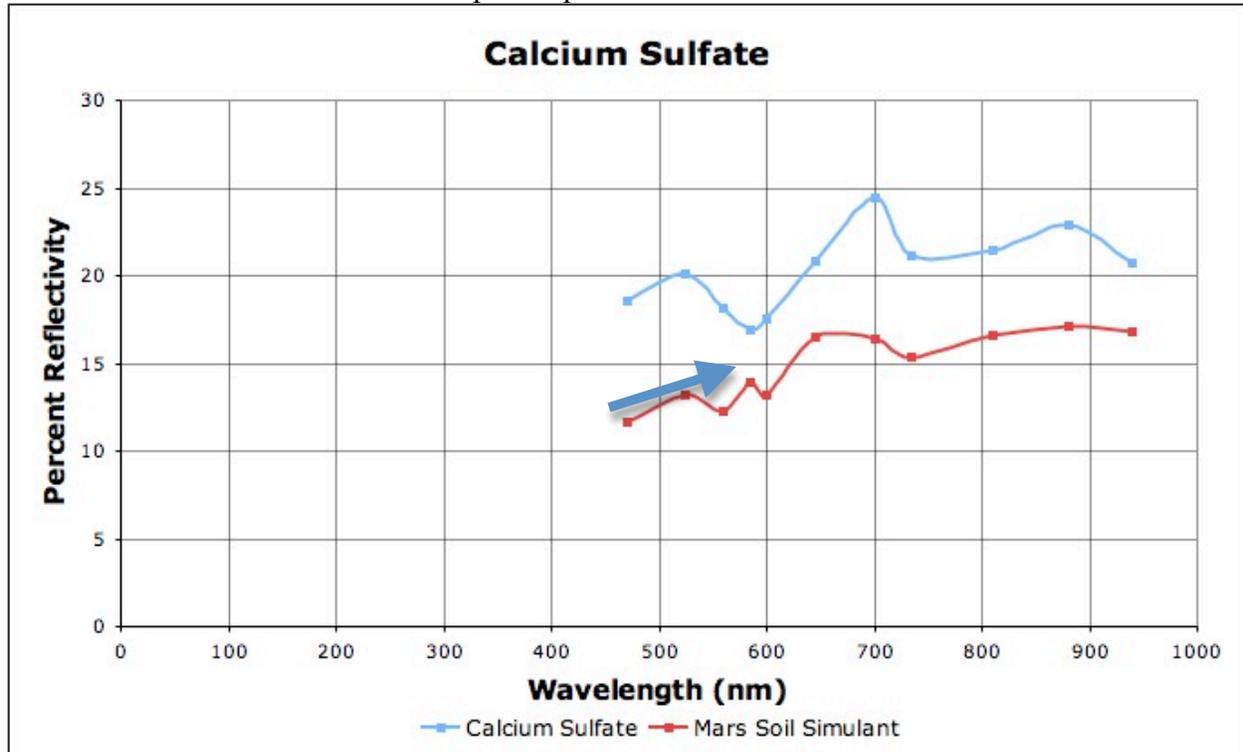
Teacher Solutions:

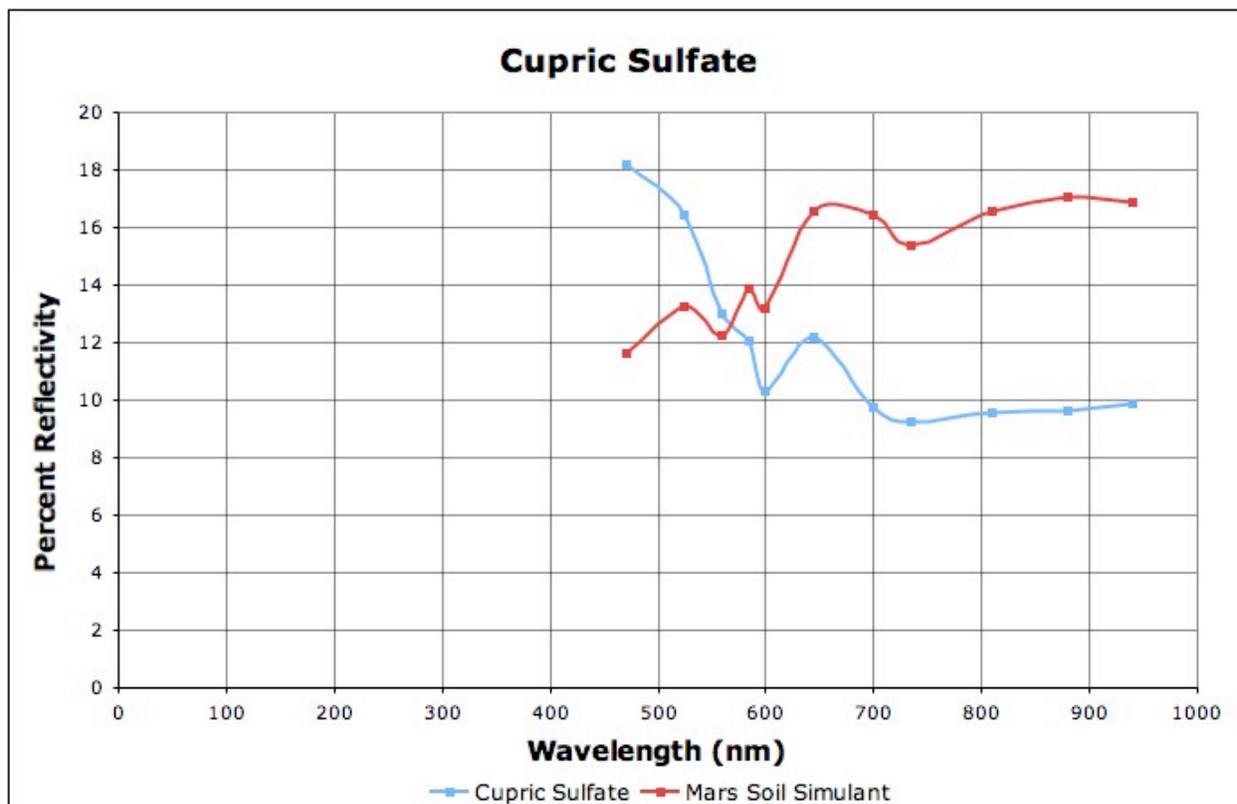
Ferric oxide and silicon dioxide are both present in the Mars soil simulant according to the company who produces it. The plots appear on the next page. Observe how the peaks and dips provide a good match to the Martian soil. Students may answer that either ferric oxide, silicon dioxide, or both are in the sample.

Wikipedia is actually a good source for students to look for potential uses of ferric oxide and silicon dioxide. Some of the potential uses for ferric oxide include making paint, explosives, and rocket fuel. Some of the potential uses for silicon dioxide include making glass and aerogel (a very light weight insulator). Allow students to be creative with their answers of how the scientists might use the material.

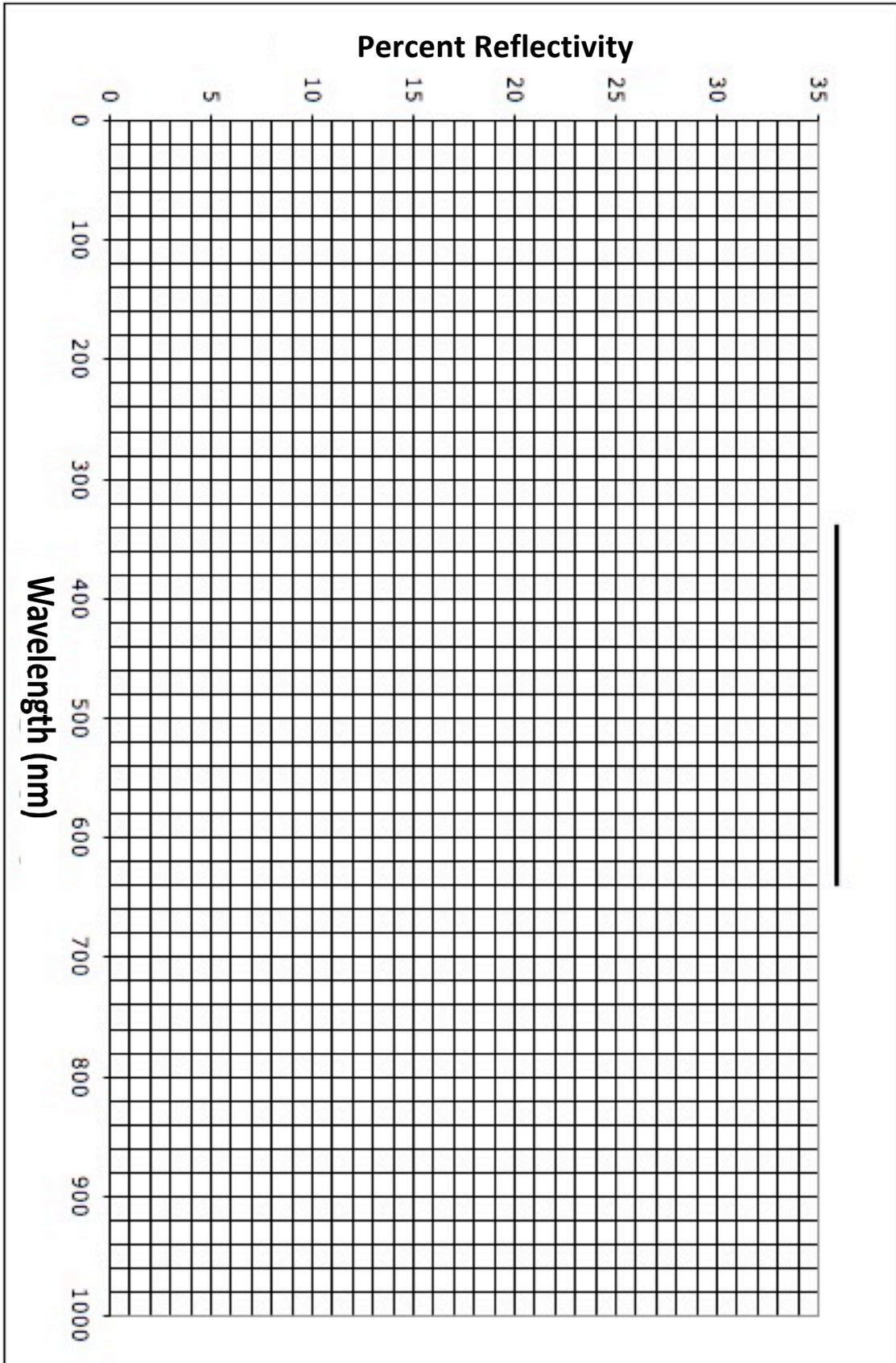


Calcium sulfate and cupric sulfate are not present in the Mars soil. The calcium sulfate has a dip at the exact wavelength the Mars soil has a peak (arrow). The cupric sulfate descends from 475-600 nm where the Mars soil has a series of dips and peaks.





Student Graph Paper



Student Handout

It is the year 2032. Humans have established a base camp in the Martian northern hemisphere in a region called Mawrth Vallis. The team collected and made measurements of some soil from a region near the camp, but wanted to confirm their measurements. In an ambitious mission, the scientists in the Mawrth Vallis base camp built a rocket to return a soil sample to Earth for analysis. Your class was selected to participate in the analysis of the sample. Your job is to determine the major components of the soil and send your results back to the Martian team using an ALTA II reflectometer, a tool similar to the one the scientists have. The scientists hope you can confirm some of the minerals that could be used at their camp and what the potential uses are. The scientists think there may be silicon dioxide, calcium sulfate, ferric oxide, and cupric sulfate in the soil, but are not completely sure because their equipment has not recently been calibrated and was recently exposed to harmful solar radiation.

PART 1

Directions

1. Collect an ALTA II reflectometer for your group.
2. When the lights are off, turn on the ALTA II and lightly press it against a hard surface. Without pressing any buttons, observe the value on the display. This is your dark voltage. Record this value on every data sheet in the dark voltage space. Later, once all measurements have been recorded, you will subtract your dark voltage reading from each measurement.
3. You and your group will go to one of the stations set up around the room.
4. Find the white paper at the first station you visit. Turn on the spectrometer and place it flat on top of the white paper. Now, press each wavelength button one at a time and record your measurements on the data sheet provided.
5. Before taking measurements, look at each sample (do not touch). Write down some observations: What overall color is it? Does it appear to have more than one color in it? What type of texture does it have? Does it look like sand, clay, or dirt? Is it clumpy or smooth?
6. Predict whether *you think* the sample is or is not a component of the Mars soil simulant.
7. Next, measure the reflectance of the sample. Start by placing the ALTA II on top of the box. Without pushing any buttons, check to make sure the dark voltage is close to the value you recorded for dark voltage in step 2. If not, some light is leaking into the ALTA II and it should be moved until the dark voltage is similar to your measurement.
8. Push down each button for each of the wavelengths and record these values in the tables provided.
9. Move to another station, and repeat steps 5-8.



Marvelous Martian Minerology

DATA SHEETS

Names: _____

Dark Voltage Reading _____

WHITE PAPER

Color	Wavelength (nanometers, nm)	White Paper Reading	White paper – dark voltage (A)
Blue	470		
Cyan	525		
Green	560		
Yellow	585		
Orange	600		
Red	645		
Deep Red	7000		
IR 1	735		
IR 2	810		
IR 3	880		
IR 4	940		

SAMPLE NAME _____

Visual observations:

Prediction:

Color	Wavelength (nanometers, nm)	Sample reading	Sample reading – dark voltage (B)
Blue	470		
Cyan	525		
Green	560		
Yellow	585		
Orange	600		
Red	645		
Deep Red	7000		
IR 1	735		
IR 2	810		
IR 3	880		
IR 4	940		



Marvelous Martian Minerology

SAMPLE NAME: _____

Dark Voltage Reading: _____

Visual observations:

Prediction:

Color	Wavelength (nanometers, nm)	Sample reading	Sample reading – dark voltage (B)
Blue	470		
Cyan	525		
Green	560		
Yellow	585		
Orange	600		
Red	645		
Deep Red	7000		
IR 1	735		
IR2	810		
IR 3	880		
IR4	940		

SAMPLE NAME _____

Visual observations:

Prediction:

Color	Wavelength (nanometers, nm)	Sample reading	Sample reading – dark voltage (B)
Blue	470		
Cyan	525		
Green	560		
Yellow	585		
Orange	600		
Red	645		
Deep Red	7000		
IR 1	735		
IR 2	810		
IR 3	880		
IR 4	940		



Marvelous Martian Mineralogy

SAMPLE NAME: _____

Dark Voltage Reading: _____

Visual observations:

Prediction:

Color	Wavelength (nanometers, nm)	Sample reading	Sample reading – dark voltage (B)
Blue	470		
Cyan	525		
Green	560		
Yellow	585		
Orange	600		
Red	645		
Deep Red	7000		
IR 1	735		
IR2	810		
IR 3	880		
IR4	940		

SAMPLE NAME _____

Visual observations:

Prediction:

Color	Wavelength (nanometers, nm)	Sample reading	Sample reading – dark voltage (B)
Blue	470		
Cyan	525		
Green	560		
Yellow	585		
Orange	600		
Red	645		
Deep Red	7000		
IR 1	735		
IR 2	810		
IR 3	880		
IR 4	940		



Marvelous Martian Mineralogy

PART 2

Earlier you made measurements of each sample. Your group subtracted the dark voltage from each measurement. Dark voltage is the number the ALTA II records without any buttons being pressed. This is called “noise.” Scientists subtract noise because it is not part of the real measurement of the instrument.

The ALTA II collects light to make a measurement. When all of the lights are off and it is pressed against a surface, no light should be collected, but the ALTA II still records a number. That number *should* be zero, but it’s not because the electronics inside make the ALTA II think that light is being collected. It’s like if your bathroom scale were set to 10 pounds before you stepped on it— You’d want to subtract that, right? We subtract the dark voltage number to find the real measurement.

You also measured the reflectivity of the white paper. Think of the white paper as being the most reflective surface, or the maximum, the ALTA II can measure. We can express all of the other measurements as a ratio of the white paper measurements. Then, we can compute how reflective the samples are compared to the white paper. This is something called percent reflectivity (%Reflectivity). If you got an 8 out of 10 on an assignment, the ratio would be 8/10 or 0.8. If we convert that to a percentage, we would multiply $0.8 \times 100 = 80\%$. This is basically the same thing:

White paper - dark voltage = A

Sample - dark voltage = B

% Reflectivity = R

$$R = (B/A) \times 100$$

OR

$$\% \text{ Reflectivity} = \frac{\text{Sample - Dark voltage}}{\text{White reading - Dark voltage}} \times 100$$



Marvelous Martian Minerology

Directions:

On the tables provided, compute the %Reflectivity (R) for each sample. Import the values for the White Paper table, and from the Sample tables. Use a calculator.

Mars Soil Sample

Color	Wavelength (nanometers, nm)	White paper – dark voltage (A)	Sample reading – dark voltage (B)	%Reflectivity $R = \frac{B}{A} \times 100$
Blue	470			
Cyan	525			
Green	560			
Yellow	585			
Orange	600			
Red	645			
Deep Red	700			
IR 1	735			
IR2	810			
IR 3	880			
IR4	940			

Silicon Dioxide

Color	Wavelength (nanometers, nm)	White paper – dark voltage (A)	Sample reading – dark voltage (B)	%Reflectivity $R = \frac{B}{A} \times 100$
Blue	470			
Cyan	525			
Green	560			
Yellow	585			
Orange	600			
Red	645			
Deep Red	700			
IR 1	735			
IR2	810			
IR 3	880			
IR4	940			



Marvelous Martian Mineralogy

Calcium Sulfate

Color	Wavelength (nanometers, nm)	White paper – dark voltage (A)	Sample reading – dark voltage (B)	%Reflectivity $R = \frac{B}{A} \times 100$
Blue	470			
Cyan	525			
Green	560			
Yellow	585			
Orange	600			
Red	645			
Deep Red	700			
IR 1	735			
IR2	810			
IR 3	880			
IR4	940			

Ferric Oxide

Color	Wavelength (nanometers, nm)	White paper – dark voltage (A)	Sample reading – dark voltage (B)	%Reflectivity $R = \frac{B}{A} \times 100$
Blue	470			
Cyan	525			
Green	560			
Yellow	585			
Orange	600			
Red	645			
Deep Red	700			
IR 1	735			
IR2	810			
IR 3	880			
IR4	940			



Marvelous Martian Mineralogy

Cupric Sulfate

Color	Wavelength (nanometers, nm)	White paper – dark voltage (A)	Sample reading – dark voltage (B)	%Reflectivity $R = \frac{B}{A} \times 100$
Blue	470			
Cyan	525			
Green	560			
Yellow	585			
Orange	600			
Red	645			
Deep Red	700			
IR 1	735			
IR2	810			
IR 3	880			
IR4	940			

Part 3

Directions:

- 1) Using a wet-erase marker and the transparency graph paper provided by your teacher, graph Wavelength vs. %Reflectivity for the Mars soil sample. Wavelength is the X-axis and %Reflectivity is the Y-axis. This is the reflection spectrum for the Mars soil.
- 2) Plot Wavelength vs. %Reflectivity on the graph paper provided for all of the other samples.
- 3) Place the Mars soil reflection spectrum (transparency graph) over each of the other spectra and compare the dips and peaks. Be very careful because some may be close to each other but not exactly at the same wavelength. Try to decide which chemicals are in the Martian soil simulant and which are not! Write down your results.
- 4) As a class, discuss your results. Did everyone come to the same conclusions?
- 5) Research one of the components of your Martian soil. Can the scientists use the soil to make useful things on their Martian base? Assume they have the necessary equipment. Write 2-3 paragraphs about what they might make and how it could be used on the base.