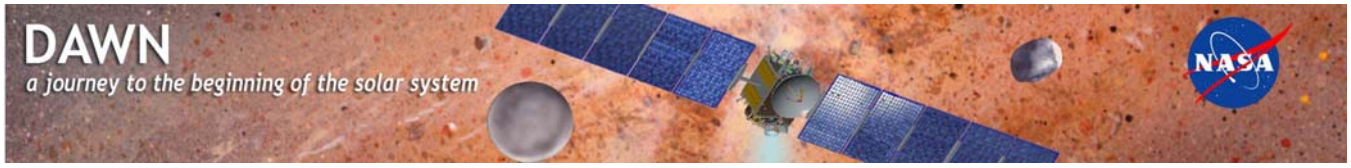

Interactions of Energy and Matter: Dawn Instrumentation

CSI

TEACHER GUIDE-BRIEFING

BACKGROUND

The presence or absence of water in soil is a concept that students are familiar with; it is a phenomenon that also relates directly to the Dawn mission. If they have watched any of the CSI or similar television programs, they know how crime scene team members collect samples and trace evidence. They have also seen the team members examining and analyzing spectrographs. In the Briefing: CSI Activity students compare and analyze some simple spectrographs, leading to more than one possible conclusion, giving them a fairly realistic simulation of science at work.

An excellent source for background on the Water Absorption Spectrum, see http://www.lsbu.ac.uk/water/vibrat.html. This article contains basic information regarding the main vibrations of molecular water vibrations in gaseous, liquid, and solid state.

In this activity, a crime was committed on the sandy shore of a lake at a local park. Your students will act as members of a crime scene investigation team that has taken a soil sample while investigating what is thought to be the scene of a crime. When two suspects were brought into the police station for questioning, one was wearing a shirt with patches of dried soil. The other had some partially dried mud on his/her jeans (See Police Photo Log).

CSI scientists used infrared spectrometry to analyze soil samples from each of the suspects' clothing. Students will use these soil absorption spectra to compare with the spectrogram of the soil sample taken from the crime scene.

Comparison of water content spectra from the three samples, measured at near-infrared (NIR) bands ranging from about 970-1940 nm (see Data Sheet 1) proves to be inconclusive. CSI scientists then decided to test the three soil samples to determine their mineral content. Since the crime scene was a sandy shore, they focused on quartz (silicon dioxide) concentration since SiO_2 is the major constituent of sand. The resulting spectra are in Data Sheet 2. CSI student scientists consider some possible conclusions regarding the crime scene, based on the sample analysis.

NSES Physical Science Standard Addressed

Transfer of energy

Light [electromagnetic radiation] interacts with matter by transmission, absorption, or reflection

Interactions of Energy and Matter

Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance.

NSES Science as Inquiry Standard Addressed

Understandings about Scientific Inquiry

Scientists rely on technology to enhance the gathering and manipulation of data

Just as the presence or absence of water and the soil silicate content was important to the CSI team as they analyzed the crime scene, the presence or absence of these compounds in Vesta's and Ceres' surface features are important to the Dawn mission scientists. Space scientists think that Vesta is a dry

rocky asteroid whereas Ceres may have some frozen water (water ice). The CSI student scientists will compare how they used infrared spectrometer to detect the presence of water and quartz in the dirt embedded in the suspects' clothing with the way Dawn scientists will use the same type of spectrometer to tell us whether or not water or quartz (and/or other silicates) are present in the surface of Ceres.

This briefing activity directly aligns with *National Science Education Standards* (NRC, 1996) content standards. The activity includes individual and class questions in which students describe how reflectance, absorption, and transmission are related which addresses a Physical Science "Transfer of Energy" benchmark for students in grades 5–8. The activity also involves students in analyzing simulated reflectance spectra and absorption spectra to help them identify water content and soil composition respectively, addressing the high school benchmark which states that "...wavelengths can be used to identify [a] substance." This activity asks students to consider multiple technologies (instruments) that are needed to gather information to either solve a crime or characterize an asteroid addressing the Science as Inquiry benchmark that states "scientists rely on technology to enhance the gathering and manipulation of data."

Materials

Copies for each student:

- Police Photo Log
- Parts 1 and 2 of Student Activity/Report Sheet for Briefing: CSI Activity
- Data Sheet 1. Infrared Reflectance Spectra of Crime Scene Soil Samples
- Data Sheet 2. Infrared Silicate Absorption Spectra of Crime Scene Soil Samples
- Table 2. The Electromagnetic Radiation Spectrum (from Overview)

Procedure

1. Divide the class into teams and give instructions about time limits for the assignment. Thirty minutes is suggested for Part 1 of the activity.
2. Distribute copies of the Part 1 Briefing CSI: Activity Sheet and ask them to read the first paragraph. as you tell them that they will be acting as crime scene investigators. The activity sheet describes the problem to be solved and includes questions to be answered.
3. Distribute the Police Photo Log to students. Debrief the content of this paragraph and the photo log. Ask what the students know from this information and what remaining questions they have.
4. Distribute Data Sheet 1. During the follow-up session, ask teams to share their answers to the Part 1 questions. Some possible answers are given in the brackets following the questions, but accept and discuss the merits of all your students' answers.

1. **The Y-axis of these spectral graphs are labeled "percent reflectance." How is reflectance related to absorption?**

   [Reflected EMR includes wavelengths that bounce back from or are redirected by the matter surface. Reflectance includes EMR wavelengths that are not absorbed by the material or transmitted through a sample of matter.]

2. **Why do you think that the dry soil sample from suspect #1's clothing showed the most reflectance of the three samples?**

   [Wet soil is usually darker in shade than dry soil because of water's absorbance of EMR. Increased absorbance usually means less reflectance.]

3. **Do the results of this water content test lead to any conclusions regarding whether or not either of the suspects could have committed the crime? Why or why not?**

   [The sample from Suspect #2 shows the same spectral pattern as the soil found at the scene, so this could be evidence that Suspect #2 has been at the crime scene.]

Since we are not sure when the crime was committed, could the mud have dried since the crime?

[This is a possibility.]

Was the difference in reflectance only indicating the difference in water content?

[Maybe the composition of the soil itself contributed to the reflectance. For example, soil with a high content of iron might be more red in color.]

Where on the suspects' clothing was the soil found—on the front, side, or back? How does this relate to the crime?

[These answers are not available from the Police Photo Log or by analyzing the spectra.]

4. **Would you feel comfortable holding either of the suspects for further questioning based on the results in Data Sheet 1?**

   [Probably not]

   What other information might you need to make the decision about the suspects' involvement in the crime?

   [Does the soil content on either or both of the suspects' clothing match the soil content of the sample taken at the crime scene?]

Part 2

1. Distribute Part 2 of the Briefing CSI: Activity and Data Sheet 2 to the students. Allow them 20–30 minutes to study the data and decide on answers to the questions.
2. During the follow-up session, ask teams to share their answers to the Part 2 questions. Some possible answers are given in the brackets following the questions, but accept and discuss the merits of all your students' answers.

1. **The Y-axis of these spectral graphs are labeled "percent transmission." What is the relationship between transmission and absorption?**

   [EMR can be reflected, transmitted, or absorbed when it reacts with matter. Absorption refers to the EMR that is absorbed by atoms and molecules in the matter with which it interacts. Transmission refers to the EMR that goes through matter. We usually think of visible light being transmitted through glass or some other transparent material. However, if you form a very thin film of a substance, such as soil, EMR that it outside the visible spectrum can be transmitted through the film.]

2. **Based on these spectra, can you determine whether either of the suspects should be questioned further? If not, what do you need to know?**

   [The soil from Suspect #1's clothing appears to be a match to that of the soil sample collected at the scene. That does not rule out the possibility that the soil on Suspect #1's clothing came from a different source. Suspect #1 should be questioned further to determine whether or not he/she can be placed at the scene of the crime when it happened. Although the mud on Suspect #2's jeans did not match the crime scene soil, he/she cannot be ruled out as an accomplice just on the basis of these two spectral analyses, especially if the two suspects have been known to work together in the past.

   Other evidence that the team should look for includes the following:

   - Did either of the suspects leave fingerprints or footprints at the scene of the crime?
   - Was their any mud or dried soil on their shoes?
   - Other trace evidence, such as clothing fibers or body tissue (DNA), should be included in the analysis.]

3. **In addition to spectroscopy, what other methods do crime scene scientists use to solve crimes?**
   [Observation, photography, wet chemistry analysis, different types of fingerprint analysis, foot print and tire tread castings, reconstruction techniques.]

4. **Why is it important to use more than one method of detection and analysis to confirm the constituents of a sample of matter?**
   [Scientific conclusions are rarely based on one set of data. They usually require confirmation from multiple sets of observations, measurements, and analysis.]

How are multiple methods similar to how the Dawn spacecraft is collecting data on the surfaces of Vesta and Ceres?

[Dawn will use multiple instruments to collect data. Any one instrument would provide incomplete information about the bodies, but together they will provide information for scientists to meet mission objectives]

Relating the CSI Activity to Dawn Objectives and Instrumentation

Continue the activity follow-up session by introducing the Dawn goals and instrumentation, using wording similar to the following:

Just as the presence or absence of water and the soil silicate content was important to your CSI team as you analyzed the crime scene, the presence or absence of these compounds in Vesta's and Ceres' surface features are important to the Dawn mission scientists. Space scientists think that Vesta is a dry, rocky asteroid whereas Ceres may have some frozen water (water ice).

Ice

When we use the term "ice" we usually mean the solid form of water. Space scientists often use the "ices" to indicate the solid form of carbon dioxide, ammonia, and other compounds that are gases in our environment as well as solid water.

Continue by asking questions similar to the following:

1. **One of the objectives of the Dawn mission is to search for ices near the asteroids' surfaces to a depth of 1 m. If the CSI scientists can use an infrared spectrometer to detect the presence of water in the dirt embedded in the suspects' clothing using reflectance and transmission, could Dawn scientists use the same type of spectrometric techniques to tell us whether or not water is present on the surface of Ceres?**
   [Yes, they can and they will, but analyzing a soil sample here on earth is a little different from carrying out the same kind of analysis in space.]

Continue to explain the answer to question #1 by saying:

Since the VIR (visible near infrared) spectrometer will be on the spacecraft orbiting above the asteroid surface, the detection will have to be carried out by remote sensor, rather than "hands on" like our CSI scientists did here on Earth.

The Dawn spacecraft will also carry a framing camera and a gamma ray and neutron detector (GRaND) spectrometer. The framing camera and the VIR spectrometer can only "see" the top of the asteroid surface, but the GRaND spectrometer can actually "look" for water ice about 1 meter into the surface.

2. **Do you think that Dawn scientists will use the same infrared wavelengths to detect water ice as those used in this CSI activity to determine liquid water content?**
   [The simple answer to this question is no because, in our CSI activity we were testing for the presence of liquid water; Dawn scientists will be looking for water ice.]

Continue to explain the answer to question #2 by using any of the information below that is appropriate to your students' background:

The way in which students answer this question will depend upon their background in chemical bonding. Those who have not studied the vibrational modes of water molecule bonds will probably think that water molecules in the solid form would absorb infrared radiation in the same wavelengths as water molecules in the liquid form. Although water spectroscopy is quite complicated, the following table summarizes some main absorption wavelengths of the three phases of water that you may use to help your students understand that absorption spectra depend upon the amount of freedom water molecules have to bend and stretch in different phases. Be aware that *these are only examples* of how detection wavelengths change with changes in physical phase and are NOT the infrared wavelengths that we used in the spectral analysis for this activity. Note that the absorption wavelengths increase for the stretching modes (v_1 and v_3) as you go from gas to liquid to solid and that wavelengths decrease for the bending mode (v_2) from gas to solid.

Teacher Note
This table is duplicated for your use in Screen 2 of the **Dawn Mission Briefing CSI Activity PowerPoint.**

Screen 2

Main absorption wavelengths of symmetric stretching (v_1), bending (v_2) and asymmetric stretching (v_3) of water molecules in three phases

Phase of H_2O	v_1	v_2	v_3
Gas	2734 nm	6273 nm	2663 nm
Liquid	3048 nm	6082 nm	2865 nm
Solid	3241 nm	6060 nm	3105 nm

For information on the Water Absorption Spectrum, see http://www.lsbu.ac.uk/water/vibrat.html.

Refer students to the information in Table 2.

The Dawn spacecraft carries a single VIR spectrometer able to cover both visible (250-1000 μm) and IR (1000-5000 μm) spectral ranges. The GRaND (Gamma Ray and Neutron Detector) Spectrometer will also be looking for evidence of water ice, using wavelengths (frequencies) of a much higher energy.

3. In addition to the possible presence of water on Ceres, Dawn scientists want to know other information about Vesta and Ceres. Let's see if we can identify which of the Dawn instruments will measure what? You may use the information in Table 2 to help you answer these questions.

*Go to Screen 3 of the **Dawn Mission Briefing CSI Activity PowerPoint** for some specific information and questions for students to consider. Use the script below as a guide.*

Screen 3

{click}The Dawn mission's science goals are to
{click} understand the conditions and processes in place at the beginning of solar system formation.
{click} Scientists also hope to gain a new understanding of the role of water in asteroid evolution.

Screen 4

{click} To meet these Dawn Mission science goals
{click} Dawn spacecraft instrumentations
{click} will utilize the ***interactions*** between different frequencies/wavelengths of the EMR
{click} and
{click} matter to make scientific measurements and analyze data

Screen 5

We learned that Dawn's Visible and Infrared (VIR) spectrometer and its Gamma Ray and Neutron Detector (GRaND) will be looking for evidence water and water ice.

Screen 6

{click} Which of the Dawn spacecraft instruments will be used
{click} to detect the presence of elements and mineral content on the asteroids' surfaces?
{click} the Framing Camera?
{click} the Gamma Ray Spectrometer and Neutron Detector?
{click} the Visible and Infrared Spectroscope?

{Allow time for students to consider the three possible answers given.}

[Both the VIR Spectrometer and the Gamma Ray Spectrometer and Neutron Detector will be useful in determining the presence of elements and mineral content. Photographs from the Framing Camera may also be useful.]

Screen 7

{click} Which of the Dawn spacecraft instruments will be used
{click} to create global topography, albedo, and color maps of the asteroid's surface ?
{click} the Framing Camera?
{click} the Gamma Ray Spectrometer and Neutron Detector?
{click} the Visible and Infrared Spectroscope?

{Allow time for students to consider the three possible answers given.}

[This is the primary objective for the Framing Camera. However, students may remember that the Infrared Spectra was also useful in identifying differences in absorbance and reflectance of different types of soil.]

Screen 8

{click} Which of the Dawn spacecraft instruments will be used
{click} to map the abundance of radioactive elements and major constituents of ices?
{click} the Framing Camera?
{click} the Gamma Ray Spectrometer and Neutron Detector?
{click} the Visible and Infrared Spectroscope?

{Allow time for students to consider the three possible answers given.}

[This is the main function of the GRaND]

Screen 9

{click} Which of the Dawn spacecraft instruments will be used
{click} to measure the asteroid's shape, volume, mass, and mass distribution?
{click} the Framing Camera?
{click} the Gamma Ray Spectrometer and Neutron Detector?
{click} the Visible and Infrared Spectroscope?

{Allow time for students to consider the three possible answers given.}

[Although the images from the Framing Camera may give us some clues about the asteroid's shape, the Doppler Shifts in the radio communication system will be used to

determine the mass distribution and concentration, thereby giving us information regarding the asteroid's gravity field.]

Screen 10

We have just learned that
{click}Meeting each of the science objectives of the Dawn mission requires
{click}More than one kind of instrumentation
{click}Measuring EMR interactions at different energy levels

4. **The information that we learn about Vesta and Ceres from the instruments on the Dawn spacecraft will be the results of "remote sensing" rather than the "hands on" experimentation that we carry out here on Earth. What are some other differences between Earth-based and space-based scientific investigations?**

   [Accept student answers, asking for their rationale if appropriate.]

Continue by describing any differences listed below that were not included in student answers.

Not only is the distance of the instruments from the sample a problem, but the distance of the instruments from the investigators also presents challenges that do not occur during an Earth-based investigation. The data collected by spacecraft instrumentation has to be transmitted to collection sites on Earth. In space there is a wider range of temperatures than that found on Earth and Cosmic rays can interfere with data-taking or transmission. Cosmic rays can also damage scientific instruments, so the instruments that are designed for use on earth must be redesigned to meet the challenge of space investigations. On Earth, instrumentation is usually stationary; whereas, the spacecraft movement with regard to the asteroid, the sun, and Earth must be taken into account when transferring information from the spacecraft to Earth and when the data is analyzed.

5. **Dawn is unique because it is using the same type of instrumentation to study two worlds. How is this part of a good experimental design?**

   [The data obtained for Vesta and Ceres by the Dawn spacecraft will be more comparable than if different instruments or spacecraft were used.]