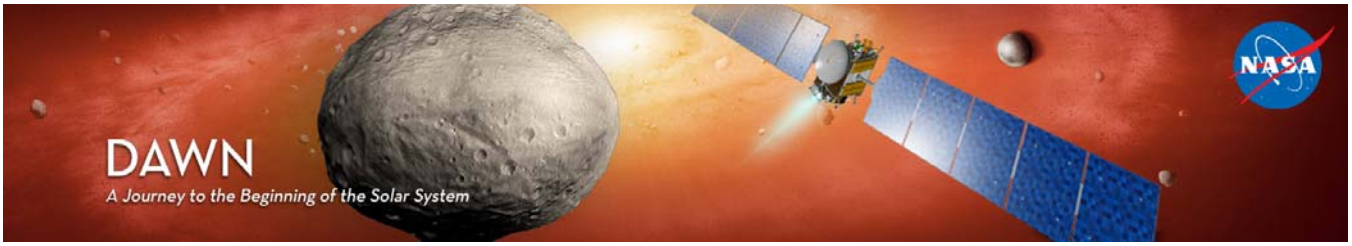

Interactions of Energy and Matter: Dawn Instrumentation

VIR Teacher Guide

TEACHER GUIDE

WHAT WILL VISIBLE AND INFRARED SPECTROMETER (VIR) "SEE" WHEN WE GET TO VESTA AND CERES?

EMR and the Dawn Mission

Electromagnetic radiation (EMR) will play a major role in accomplishing the goals of the Dawn Mission. The Dawn spacecraft instrumentation payload utilizes the interaction of specific ranges of electromagnetic radiation with the ***matter*** that comprises Ceres and Vesta. When EMR interacts with matter, ***radiation*** is absorbed or reflected only at wavelengths corresponding to the discrete amounts of ***energy*** that are related to the constituents of the matter. These wavelengths can then be used to identify the components of a given substance.

The scientific data that results from these interactions will enhance our knowledge of Vesta and Ceres by providing information about their surface composition and mineralogy, surface modification and surface ages. When this information is incorporated into what is already known, either it will substantiate current scientific theories of asteroid origins and geologic processes or it will form the basis for new models.

Dawn Mission Objectives

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

Most science curricula emphasize how we use electromagnetic radiation in our everyday lives, using illustrations such as radios, x-ray machines, microwaves, ultraviolet and infrared lamps. The materials in this module will introduce students to the ways that scientists, engineers, and technologists "in the real world" design instrumentation that utilize the interactions between different frequencies/wavelengths of the EMR and matter to make scientific measurements and analyze data. This section of the *Interaction of Energy and Matter: Dawn Instrumentation* module is designed to help your students understand more about how the ***Visible*** and ***Infrared Spectrometer*** (VIR) aboard the Dawn Spacecraft operates and what it will help us "see" when the spacecraft reaches Ceres and Vesta.

VIR

Primary Objective—study the surface mineralogical composition of Ceres and Vesta in order to understand how these bodies evolved.

Options for using the VIR *Interaction of Energy and Matter* materials

The VIR *Interaction of Energy and Matter materials* may be used in three ways:

1. Use the VIR PowerPoint presentation to engage the whole class in how this instrument in the Dawn Spacecraft payload utilizes the interaction of specific ranges of electromagnetic radiation with the matter to identify the composition of Ceres' and Vesta's ***regolith***. Have individual students complete the observation sheet handout as they watch the presentation. This option, designed to be incorporated into your study of electromagnetic radiation or your study of matter-energy interactions, can be completed in 30 minutes of class time.

2. Divide the class into groups of two or three to view the VIR PowerPoint presentation with the Student Version of the script and, as a group, complete the observation sheet handout. If you select this option, you will probably wish to review the characteristics of electromagnetic radiation using the information in *The Electromagnetic Spectrum* at http://dawn.jpl.nasa.gov/DawnClassrooms/3_instrument/images/electromagnetic_spectrum2.jpg and in the *Characteristics of EMR* in Appendix A of this guide before dividing the class into groups. For more information on the electromagnetic spectrum, you can also use the interactive found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html. If you use the students' observations as the basis for a class discussion of the applications of electromagnetic radiation and/or matter-energy interactions, this option can be completed in one 50-minute class session.
3. Divide the class into groups of two or three. Assign each group to view one of the series of PowerPoint presentations that feature the instruments—GRaND, VIR, and the Framing Camera—in the Dawn Spacecraft payload. They should complete the observation handout as a group for the instrument they are assigned. If you select this option, you will probably wish to review the characteristics of electromagnetic radiation, using the information in the *Characteristics of EMR* in Appendix A of this guide, *The Electromagnetic Spectrum*, and the website mentioned in step 2 before dividing the class into groups. If you use the students' observations as the basis for a class discussion to compare the applications of electromagnetic radiation matter-energy interactions in the different payload instruments, this option may require more than one 50-minute class session.

Two optional activities—"Background on Infrared Radiation" (from the Genesis education module, instructions below) and "Using a Remote Control to Investigate Infrared Radiation" (Appendix C, instructions below)—may be used to increase your students' background in Infrared Radiation. Using these activities will also increase the necessary class time, depending upon your selection of the activities and the depth to which you wish to cover the concept.

Materials

- Handout: Print PowerPoint slide three entitled *The Electromagnetic Spectrum*
- Student Text: *Infrared Radiation: Here Comes the Heat* found here: http://genesismission.jpl.nasa.gov/educate/scimodule/PlanetaryDiversity/plandiv_pdf/HereComesHeatST.pdf
- VIR PowerPoint presentation from the series entitled *Interaction of Energy and Matter: Dawn Mission Instrumentation*
- *Student Report Sheet: VIR* to record observed interactions of energy and matter from the VIR PowerPoint presentation
- Optional: *Student PowerPoint Script: VIR*
- Optional: Interactive website on the electromagnetic spectrum found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html
- Optional: *VIR Interactive* to reinforce the concepts introduced in the *VIR PowerPoint*

Materials for using *Background on Infrared Radiation* activity*:*

- Handout copies of "Infrared Radiation: Here Comes the Heat" student text from the Genesis education module *Planetary Diversity* located at http://genesismission.jpl.nasa.gov/educate/scimodule/PlanetaryDiversity/plandiv_pdf/HereComesHeatST.pdf
- SIRTF NASA JPL video, "Infrared: More Than Your Eyes Can See" located at: http://www.youtube.com/watch?v=wWxMj64sKgM.

For the Procedure for using *Background on Infrared Radiation* Activity, see Appendix B.

Materials for *Using a Remote Control to Investigate Infrared Radiation* activity:

- Television set with an infrared remote control
- Flashlight or laser
- Large, clear container of water
- Powdered coffee creamer
- Ten sheets of white typing paper
- Light bulb, 100 Watt
- Flat glass plate and mirror (optional)
-

For the Procedure for *Using a Remote Control to Investigate Infrared Radiation*, see Appendix C.

Note: If you plan to use the assessment created for this module, please ask your students to keep all of their activities and handouts for use in completing the assessment entitled *Concept Maps: EMR Matter-Energy Interactions and Relationships.*

Procedure

Using the VIR PowerPoint presentation with whole class

1. Start the *Interaction of Energy and Matter: Dawn Mission Instrumentation* PowerPoint presentation. You will find a suggested script for each screen and cues for controlling the forward progress of the presentation in text boxes.

2. As students view the title page of the VIR PowerPoint presentation:
   VIR is one of the scientific instruments in the payload of the Dawn spacecraft. The Dawn Mission is designed to increase our understanding of the conditions and processes that were happening during the solar system's earliest epoch. Surface mineralogical data from VIR will give scientists a better understanding about how two large asteroids, Vesta and Ceres, evolved.

3. {click to Slide 2}
   The VIR is a Visible and Infrared Imaging Spectrometer. In this section, we will be learning more about the VIR, including what it does and how it does it.

4. {click to Slide 3}
   Have students examine Slide 3 and/or handout copies of the *The Electromagnetic Spectrum*. You may also want students to review the interactive information found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html.
   If this is your first lesson in the Exploration phase of this module, introduce (or ask students to review) the characteristics of electromagnetic radiation, using the information in the *Characteristics of EMR* located in Appendix A of this guide and explore the interactive information presented at the website above.

   {The answers to the **bolded student questions** are not part of the Student Version of the script. Students are prompted to answer these questions on their *VIR Student Report Sheet*.}

   What region of electromagnetic radiation (EMR) from Ceres and Vesta will the VIR measure?
   {Wait for student answers.}
   [The table indicates that VIR will detect and measure radiation reflected from the surface of Ceres and Vesta in the visible and infrared regions of EMR.]

   What frequency and wavelength regions of EMR are classified as visible radiation?
   {Wait for student answers.}
   [Wavelengths in the range of 10^{-6} m and frequencies in the range of 10^{15} hertz.]

What frequency and wavelength regions of EMR are classified as infrared radiation?
{Wait for student answers.}
[Wavelengths in the range of 10^{-5} m and frequencies in the range of 10^{12} hertz.]

How does the energy of visible and infrared compare with the energy of the rest of the EMR waves? {Wait for student answers.}
[Visible and infrared radiation have medium energy compared to the rest of the EMR.]

5. {click to Slide 4}
   What will the VIR do when Dawn gets to Vesta and Ceres?
   {click}
   The Visible and InfraRed (VIR) imaging spectrometer will measure the mineralogical composition of the surfaces of Vesta and Ceres. Using a combination of visible and infrared radiation, it will
   {click}
   - image the surfaces of Vesta and Ceres and determine the spatial distribution of the various mineralogical types found there;

   {click}
   - determine the physical texture and nature of surface particles, which can provide information about the conditions under which Vesta and Ceres were formed; and

   {click}
   - determine the mineral composition of surface materials, including silicates, hydrates and other minerals, in the geological context.

6. {click to Slide 5}
   The VIR spectrometer is designed to investigate both visible and infrared regions of the electromagnetic spectrum because the minerals that compose the surface of Vesta and Ceres show ***absorption bands*** in both regions.

   The VIR
   {click}
   weighs 27 kg, and has three modules:

   {click}
   the optical system, which we will examine more thoroughly in the next few slides;

   {click}
   the proximity electronics, which interface with the main electronics and drive the radiation detectors, the scan mirror and the cover mechanism;

   {click}
   and the cryocooler, which maintains the temperature of the instrument between 70 and 75 K so the detectors can operate.

7. {click to slide 6}
   This is a diagram of the VIR Optical System.

   The system combines a ***Shafer telescope***,
   {click}
   which is lightweight and very compact, with an ***Offner grating spectrometer***,
   {click}
   in a single ***optical head***. One advantage of this unique instrument arrangement is that it makes the VIR is very compact, measuring only
   {click}
   22 cm
   {click} {click}
   by 20 cm.

   Reflected light
   {click}
   from the asteroid's surface enters the Shafer telescope, and strikes the primary mirror,
   {click}
   also called the scanning mirror. This design utilizes the beryllium technology first introduced by Ferrari to make Formula 1 cars lighter in weight. Beryllium's thermal and mechanical characteristics make the mirror weigh less than an equivalent mirror made of aluminum. The beryllium mirror is also less flexible and less sensitive to temperature changes than an equivalent aluminum mirror.
   {click}
   The telescope also uses five aluminum mirrors mounted on an aluminum optical bench. Aluminum was used because it has a low density, high reflectivity, and high durability.

   {Students are prompted to answer this question on their *VIR Student Report Sheet*.}
   What interactions of matter and energy are described in this explanation of the VIR?
   {Wait for student answers.}
   Energy is reflected off the surface and detected by the Shafer telescope. The electromagnetic radiation then reflects off the primary mirror and five aluminum mirrors.

8. {click to slide 7}
   Focused light from the telescope enters the Offner spectrometer through
   {click}
   a slit and travels through a
   {click}
   spherical glass convex ***diffraction*** grating. The grating bends the visible and infrared waves coming into the telescope to create a spectrum of the radiation.

   Because VIR measures both visible and infrared reflected radiation, two different groove densities are etched on a single grating. The central 30% of this enlarged image of the grating
   {click}
   is etched with a higher groove density. That is, there are more lines per millimeter. This generates the high spectral resolution needed in the visible channel.
   {click}
   The infrared channel, which utilizes the outer 70% of the grating, is etched with a lower groove density. The larger IR collecting area compensates for the lower solar radiation in this region.

{Students are prompted to answer this question on their *VIR Student Report Sheet*.}
What do the diffraction gratings (matter) do to the visible and infrared rays (energy) after they enter the VIR?
{Wait for student answers.}
The diffraction gratings bend the light, split it, and spread it out so that the radiation detectors can "see" what energies are present in the light.

9. {click to slide 8}
VIR uses two radiation detectors, a silicon ***charge-coupled device***,
{click}
or CCD,
{click}
to detect and image visible radiation in wavelengths from 0.25 to 1 micrometer and
{click}
a mercury cadmium telluride IRFPA, short for ***Infrared Focal Plane Array***,
{click}
to detect radiation in the infrared region from 0.95 to 5 micrometers. The IRFPA is cooled to 70 K by the cryocooler. The CCD is operated at 155 K and is mounted directly on the spectrometer. For a review of how units of measurement compare to each other, see the Wavelength Conversion Factors chart found at
http://dawn.jpl.nasa.gov/DawnClassrooms/3_instrument/pdfs/Wavelength_Conversion_Factors.pdf

{Students are prompted to answer this question on their *VIR Student Report Sheet*.}
Why is it necessary to use two radiation detectors?
{Wait for student responses.}
The VIR instrument has two radiation detectors because it detects two different forms of electromagnetic radiation: visible and infrared.

10. {click to slide 9}
VIR shares a data processing unit, a DPU, with another instrument on Dawn, the Framing Camera, to save payload mass. The DPU produces spectroscopic graphs like the one shown here, in which the
{click}
percentage reflection is plotted against
{click}
the radiation wavelength.

In the part of the graph labeled "visible light"
{click}
the red line
{click}
is the spectrum for red sandstone, an Earth rock that reflects more red light than blue light. This is the reason that red sandstone appears red to us.

Andesite
{click}
and basalt, volcanic rocks common on Earth,
{click}
don't reflect any one color of light much more than any other color so they appear dark gray or black to our eyes. Based on the connection between ***HED meteorites*** and spectra of Vesta obtained from space-based telescopes, scientists expect to find basaltic rock on Vesta.

Because the color of rock in visible light does not indicate the kinds of minerals that are present in the rock, the VIR will also measure reflected radiation in the
{click}
infrared region of the electromagnetic radiation spectrum.

The “dips” or “troughs” in the infrared spectrum can help us identify the minerals that are present in the rock. At what wavelengths do sharp troughs appear in the sandstone spectrum?
{Wait for student answers}

That’s right, at
{click}
1.4
{click}
1.9 and
{click}
2.2 microns.

Do you see that the spectrum from limestone, another common Earth rock, shows the same troughs at 1.4 and 2.2 microns, but not at 1.9 microns?

The dips in the spectra at these wavelengths indicate that water is present in both sandstone and limestone. This also indicates that they are sedimentary rocks that formed underwater.

At what wavelengths are there smooth dips in the andesite and basalt spectra?
{Wait for student answers}
That’s right, at
{click}
0.9 and
{click}
1.0 microns. These smooth troughs are indications that iron and magnesium are present in these rocks.

With clues like these, scientists can determine the chemical and mineral makeup of a rock—which then become clues to the puzzle of the geologic history of the rock.

11. {click to slide 10.}
VIR is one of the instruments on the Dawn Spacecraft that will utilize the interactions of energy and matter to collect scientific data about Vesta and Ceres.
{click}
{Students are prompted to write their answers on their VIR Student Report Sheet.}
What interactions of matter and energy are described in this explanation of VIR’s output? Are there any other interactions of matter and energy that were described in this PowerPoint explanation of VIR?
Possible answers include the following:
Energy interacting with matter
    - The reflection of EMR from the surfaces of Vesta and Ceres.
    - The reflection of EMR off the aluminum mirrors as it moves through the telescope and is focused on the spectroscopic slit.
    - The diffraction of EMR to form a spectrum.
    - The interaction of EMR with the detectors—the visible CCD and the IRFPA.

Wrap-up Session

1. If you used this PowerPoint presentation either as a class or as groups studying the VIR instrument, relate this information as an application of your study to electromagnetic radiation and matter-energy interactions.
2. If you used this PowerPoint presentation as one of three that explained the matter-energy interactions of instruments in the Dawn Spacecraft payload, have each group of students report their findings and make comparisons of the findings as they relate them to the electromagnetic spectrum and matter-energy interactions.
3. Have students go to the *VIR Interactive* found in the *Interaction of Energy and Matter: Dawn Instrumentation* module at http://dawn.jpl.nasa.gov/DawnClassrooms/3_instrument/index.asp. The first sequence shows the orbiter imaging the surface. The second animation demonstrates how electromagnetic energy moves through the VIR instrument. Have the students refer back to the VIR PowerPoint script for clarification of what they are seeing in the animation. Finally, have students view the sample VIR Data Cube (click on bottom right hand box in image entitled "View VIR Data" using data from Earth as an example). Use the Spectral Profiles of the to discuss how different materials (i.e. clouds, the ground, trees, oceans) interact with visible and infrared light.

More information about VIR

The VIR, Visible and Infrared imaging spectrometer of the Dawn mission, was constructed in Italy by **Istituto Nazionale di Astrofisica** (**INAF) Rome and Galileo Avionica—Florence**, a scientific-industrial consortium financially supported by the Italian Space Agency.

What can scientists learn about Vesta and Ceres by analyzing the information from VIR?

Analysis of spectral and spatial resolution data from VIR will help scientists identify more precisely the surface geology on Vesta and Ceres, which will enable them to understand how these asteroids evolved.

Determination of the reflectance spectra from Vesta may lead to confirmation that meteorites known as HEDs are fragments of Vesta. HEDs are basaltic meteorites that include Howardites, Eucrites, and Diogenites. Study of the HED meteorites found on Earth could then contribute to an understanding of Vesta's structure and evolution.

The detection of hydrated minerals on Ceres would indicate that water played a role in the history of Ceres' formation.

Definition of Terms

Absorption bands—A series of very closely spaced absorption lines resulting from the absorption of light by molecules

Charged-coupled device (CCD)—A light-sensitive integrated circuit for storing and displaying the data of an image

Diffraction—The deviation of a wavefront from the path predicted by geometric optics when an opening or an edge of an object restricts a wavefront

Electromagnetic radiation (EMR)—"Waves" of electrical and magnetic "disturbance", radiated as visible light, radio waves, or any other manifestation of the electromagnetic spectrum

Energy—The capacity of a physical system to perform work. Energy exists in several forms such as heat, kinetic or mechanical energy, light, potential energy, electrical or other forms

Grating spectrometer—A spectrometer that uses diffraction grating (rather than beam splitters) to separate light into a spectrum of specific wavelengths

HED meteorites—HED meteorites are basaltic meteorites likely from Vesta. The group includes Howardites, Eucrites, and Diogenites

Infrared focal plane array (IRFPA)—A two-dimensional array of infrared sensitive photovoltaic elements

Infrared spectrometer—A spectrometer is an apparatus for observing the emission of particular wavelengths of light. Infrared spectrometry observes the emissions in the infrared region of the electromagnetic spectrum, with wavelengths from about 0.3 mm to 1000 mm

Matter—Any substance that has mass and occupies space

Offner spectrometer—A spectrometer is an apparatus for observing the emission of particular wavelengths of light. The Offner spectrometer consists of a relay mirror and a spherical convex diffraction grating, both made of glass, designed to analyze reflected light in both the visible and infrared EMR ranges

Optical head—A collection of input optics, the mirrors and lenses designed for various functions, all aimed at the same spot on a specimen

Radiation—Energy that comes from a source and travels through some material or through space; light, heat and sound are types of radiation

Shafer telescope—A four-mirror telescope with mirrors that correct for spherical aberration, coma, and astigmatism. The primary mirror is a scanning mirror driven by a torque motor. It is used to focus the light on the slit of spectrometer

Visible spectrometer—A spectrometer is an apparatus for observing the emission of particular wavelengths of light. Visible spectrometry observes the emissions in the visible region of the electromagnetic spectrum, with wavelengths at about 390 – 750 nm

What is a Charge-Coupled Device (CCD) and what does it do?

A charge-coupled device (CCD) is a light-sensitive integrated circuit that produces the data for an image in such a way that each pixel (or picture element) in the image is characterized by an electrical charge, the intensity of which is related to the amount of light reflected by the target.

The CCD functions in two phases—exposure and readout. During the exposure phase, tiny photosites with light-sensitive diodes convert photons of EMR into electrons, *i.e.,* electrical charge. After the exposure time is passed, the photosites are read out one line at a time.

A ***frame transfer CCD*** has a hidden, not normally used, area containing as many sites as the area exposed to light. In the Dawn version, it has a tungsten cover to protect it from protons and other high-energy cosmic particles. When the exposure time is up, the sites are transferred very rapidly to the hidden area. Here, safe from any incoming light, photosites can be read out at any speed necessary to correctly measure the site's charge. At the same time, the exposed part of the CCD is collecting light again, so there is no delay between successive exposures.

Appendix A
Characteristics of EMR

- Electromagnetic radiation is made of transverse waves (similar to water waves) that travel at the speed of light.
- Electromagnetic radiation is classified into types—radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays—according to the frequency (or wavelength) of the radiation. For more explanation, see the Electromagnetic Spectrum chart found here: http://dawn.jpl.nasa.gov/DawnClassrooms/3_instrument/images/electromagnetic_spectrum2.jpg and/or the interactive information found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html
- The frequency of electromagnetic radiation is inversely related to the wavelength of the radiation. See the websites referenced above.
- The energy of electromagnetic radiation is directly proportional to the frequency of the wave.
- Electromagnetic radiation interacts with matter by transmission, absorption, or reflection.

Depending upon the age and background of your students, these characteristics should be forthcoming:

- Electromagnetic radiation consists of an electrical field that varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field oriented at right angles to the electrical field.
- Electromagnetic radiation has energy and momentum, which may be imparted when it interacts with matter.
- Electromagnetic waves can impact matter, causing atoms to vibrate, release heat, or cause electrons to oscillate, depending upon the wavelength of the radiation.

Appendix B
Procedure: Background on Infrared Radiation

1. Ask students to read "Infrared Radiation: Here Comes the Heat" from the Genesis education module *Planetary Diversity* located at http://genesismission.jpl.nasa.gov/educate/scimodule/PlanetaryDiversity/plandiv_pdf/HereComesHeatST.pdf

2. After reading of the student text, have students answer questions similar to the following:
   a) Is infrared radiation harmful to one's eyes? Explain your answer.
   b) How does infrared radiation differ from visible light waves?
   c) Can infrared radiation be reflected?
   d) Can infrared radiation be diffracted?
   e) Can infrared radiation be absorbed?
   f) How do humans detect infrared radiation?

3. In order to help answer some of the above questions, have students complete the activity, "Using a Remote Control to Investigate Infrared Radiation" as described in Appendix C in the lab or as homework. In this activity adopted from the NASA Cassini mission "Ways of Seeing" CD ROM, students will discover how infrared radiation behaves compared to visible light.

4. Have students compare their answers with what is shown in "Infrared: More Than Your Eyes Can See" located at: http://www.youtube.com/watch?v=wWxMj64sKgM. This is a SIRTF NASA JPL video presented by Dr. Michelle Thaller about infrared radiation.

Appendix C
Procedure for Using a Remote Control to Investigate Infrared Radiation

1. Darken the room as much as possible. Stand about 1 meter (3 feet) from the TV screen and use the remote control to turn the television on and off. Try shining the flashlight onto the darkened television screen. Observe what happens in each trial.

2. Hold up a sheet of paper. Will visible light pass through the paper? Test your prediction by trying to shine the flashlight through the paper to the (dark) TV screen. Will infrared radiation pass through paper? Test your answer by holding up the paper and trying to turn on the television. Keep adding sheets of paper to the stack. What happens?

3. Hold the remote control near the television, but point it in the opposite direction. Use one sheet and then multiple sheets of paper to try to reflect the signal back toward the television. Does the remote control turn on the TV? Use the flat glass plate and the mirror to try more experiments with reflection. Try bouncing the beam off a wall or the ceiling. Try the same experiments with the flashlight. What do you notice?

4. Do people block the remote's infrared signal? Put a person between you and the television. Try to use the remote to turn on the television. Does it work? Can you reflect the beam off a person and back to the TV?

5. Hold the container filled with water in front of the remote. Does the water affect the transmission? Shine the flashlight through the water. Add enough coffee creamer into the water to block the light from the flashlight. Make sure that you stir the creamer into the water. Try to turn on the television with the remote again. Does the container of water and creamer block the infrared radiation?