



# Dirty Ice or Icy Dirt? Teacher Guide



## GOAL

Students assess whether the Martian surface around high latitude regions is more like dirty ice, icy dirt, or something else based on both Mars data and student-made physical models.

## OBJECTIVE

- Based on the soil moisture content of Earth soils (measured in water weight percent, or wt% H<sub>2</sub>O), students will determine whether the Martian surface is composed more of dirty ice or icy dirt at polar locations. Students will create physical models, which will be used to interpret Earth environments as well as the possible nature of surface conditions at the Martian poles.

## NATIONAL SCIENCE STANDARDS

Grade Level	Content Standard	Developing Student Understanding Area	Underlying Fundamental Concepts and Principals
5 - 8	Science as Inquiry	Understandings about scientific inquiry	Mathematics is important in all scientific inquiry.
5 - 8	Science as Inquiry	Abilities necessary to do scientific inquiry	Develop descriptions, explanations, predictions, and models using evidence.
5 - 8	Earth and Space Science	Structure of the earth system	Soils are often found in layers, with each having a different chemical composition and texture
5 - 8	History and Nature of Science	Nature of Science	Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
9 - 12	Science as Inquiry	Abilities necessary to do scientific inquiry	Design and conduct a scientific investigation.
9 - 12	Science as Inquiry	Understandings about scientific inquiry	Mathematics is essential in scientific inquiry.
9 - 12	Science and Technology	Understandings about science and technology	Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.
9 - 12	History and Nature of science	Nature of scientific knowledge	Scientific explanations must meet certain criteria. They must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied.

## TIME FRAME

- 1 class period (50 minutes)



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## MATERIALS

- Triple beam balances or digital scales (1 per 2-3 groups)
  - Clear plastic cups containing soil samples (1 per group)
  - Clear plastic cups containing water (1 per group)
  - Frozen pre-made samples of under-saturated soil (1-4 per class)
  - Frozen pre-made samples of saturated soil (1-4 per class)
  - Frozen pre-made samples of over-saturated soil (1-4 per class)
  - Frozen pre-made samples of soil mixed with crushed or shaved ice (1-4 per class)
  - PowerPoint slides or overhead transparencies of the following:
    - Visual map of Mars
    - GRS hydrogen map of Mars
  - Copies of Student Guide (1 per student)
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## BACKGROUND

Scientists continue to gather more data about the atmosphere and surface of Mars. The Mars Gamma Ray Spectrometer (GRS) has been able to measure down to tens of centimeters below the Martian surface, giving scientists a new perspective on the elemental composition of the near-surface of the planet. Prior to GRS, the existence of buried frozen water ice was theorized based upon physical and thermodynamic arguments. Because visible light detects only the very top surface of Mars, visual maps of high latitude regions show a small permanent water ice cap at the North Pole and a larger permanent carbon dioxide ice cap at the South Pole of Mars (see “Remote Sensing Ices on Mars” Activity). The areas surrounding these caps appear as brown dusty or soil-like material. However, GRS can measure down below this surface soil layer. We now have gamma ray data indicating that there are large amounts of hydrogen in the form of water ice buried at high latitude regions. Indeed, current estimates are that between 30-70 wt% H<sub>2</sub>O

is located poleward of 60° latitude at both poles.

A question resulting from this data is whether this water rich surface is more like dirt with water ice filling the pore spaces (icy dirt) or more like ice in which dirt is sprinkled (dirty ice). A second question is why the ice rich areas appear brown in visual images. What is the Martian surface like in these polar regions? Is it icy dirt, dirty ice, or something else?

This lesson provides students the opportunity to delve into these questions on their own. Through the lab activity, students will create physical models or analogues and draw conclusions based upon observable data. Measurements will be made in units of water weight percent (wt% H<sub>2</sub>O), which is similar though not exactly the same as soil porosity. Soil porosity is the volume of pore space (or air space between soil grains) contained within a given volume of soil. Water weight percent is the mass of water contained within a bulk mass of both water and soil.



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Outlined below are the different degrees of soil saturation.

- Under-saturated: When soil contains a small amount of water, empty pore space remains so that the soil can still absorb water.
- Saturated: As more water is added to the soil, the soil will reach a point at which it can no longer “soak” up the water because all of the pore space has been filled.
- Over-saturated: After all the pore space has been filled, excess water will sit on top of the saturated soil.

Soil moisture tells us about the water weight percent, either liquid or solid, contained at the surface. For example, desert soil during the dry season may have a low water weight percent, whereas a location with pure ice/snow pack would have 100 wt% H<sub>2</sub>O and no soil.

On Earth, soil typically becomes saturated between roughly 1-30 wt% H<sub>2</sub>O. However, GRS measurements indicate between 30-70 wt% H<sub>2</sub>O is buried in the polar regions. Through the lab activity and comparisons to situations here on Earth, students should conclude that the surface at these arctic regions is over-saturated and more like dirty ice than icy dirt.

One question that may arise in your class is how the soil became so water rich given that the current climate of Mars is very dry and cold. This topic is currently being debated by scientists. One model to explain the water rich regions at the poles has to do with changes of the axial tilt of Mars, which can vary from between 15° and 60° over 100,000 year time periods. Such drastic changes may have led to climate change that could affect the temperatures and moisture in the atmosphere making for a warmer and wetter Mars where snowfall may have been possible.

It is important to note that while the amount of past snow accumulation is still

unknown, scientists do know that the process is not occurring currently on Mars. In order to account for dirt found within the frozen water, scientists speculate that there may have been past periods of snowfall along with mixing from dust storms. As the climate gradually became colder, the stability of solid water changed, and began to evaporate leaving behind lag deposits. Lag deposits are layers of dust and soil left behind after any icy materials have evaporated away. A region of buried water ice covered by lag deposits of darker dust and soil materials would appear dark at visual wavelengths even though GRS can detect the buried water ice underneath.

Over time, alternating layers of lag deposits and layers rich in water ice may have accumulated at the near surface of Mars. These layers would have formed as Mars experienced alternating periods of warmer, wetter climates and colder, drier climates. This proposed model is based on theories and assumptions as well as processes we know occur on Earth. Until scientists are able to dig into the Martian surface, which will occur during summer 2008 with the Phoenix Mars Lander mission, the nature of the high latitude regions of Mars will remain a mystery.



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## TEACHER PREPARATION

### 1) Collecting soil samples

For this lab, it is recommended that at least three or four types of soil be used (for example, fine grain clay, medium grain sand, coarse grain gravel, etc). If you are having difficulties finding fine grain sand, you can use a mesh sieve to separate finer grains from coarser grains. Different soils will produce a variety of water weight percent measurements that will be useful in the class discussion related to the lab. Put the soil samples into containers for students to measure out on the lab day. You may give students the choice of which soil samples to measure, however it is important that all samples are tested. Alternately, you may have students find their own soil samples if time permits. Ideally, soil samples should be dried before conducting the experiment. This can be done by placing the soil samples under a heat lamp until the soil has dried.

### 2) Activity worksheets

Set up a computer projector system to show the PowerPoint slides or make color overheads of the Mars GRS hydrogen map and Mars visual map. Photocopy the three handouts: “Water Weight Percent Lab”, “Water Estimates on Earth”, and “Water Estimates on Mars” for each student or group. The worksheets can be completed individually, within a group, in a science notebook, or as a class discussion.

### 3) Preparing frozen soil samples

Frozen samples need to be made at least one day in advance. At least four samples should be made per class. If you have enough freezer space and time, samples can be made for each group instead. For the first three samples (under-saturated, saturated, and over saturated), place similar amounts of one of the soil samples into three different cups. In the cup representing under-saturated soil, add enough water to only dampen the dirt. In the saturated sample, add enough water so that the soil can no longer absorb the liquid and the water is even with the top of the soil but that none is on top of the soil. For the sample that is over-saturated, add water until there is a visible distinction between the water and the soil so that the water rests on top of the saturated soil. You can calculate the water weight percent of each of these if you like. To do this you will need to measure the dry dirt, measure the dry dirt plus water sample, and take the difference between the two samples to obtain the water weight. To calculate the water weight percent of your sample, use the following formula:

$$\text{Water weight percent (wt\% H}_2\text{O)} = \frac{\text{Water Weight}}{\text{(Water Weight + Soil Weight)}} \times 100\%$$

Put the three samples in the freezer.

The optional fourth sample is a representation of soil and frozen water mixed together. This model, like the previous three, is just another potential model of the Martian surface. Mix crushed or shaved ice with a sprinkling of soil. You do not need to add too much soil. Again, if you were to melt the ice in this cup, the soil should be clearly over-saturated. In



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addition, the finer the crushed ice is, the better the model will be. After mixing the soil and crushed ice, put it in the freezer with the other three samples. Be sure to label all samples.

#### 4) **Lab Set Up**

Each lab table should have water, a triple beam balance/scale, and clear plastic cups. You may need to have multiple groups sharing the balance if you cannot get enough to use for the class.

### **SUGGESTED TEACHER PROCEDURES**

#### 1) **Introduction**

To start the activity, show students the visible map of Mars using either the PowerPoint slide or the overhead transparency. Ask students to describe features that they see on the map. Answers may include impact craters, volcanoes, canyons, mountain ranges, water features, ice caps. Focus in on the ice caps and explain to students that these are the permanent ice caps that remain at each pole during the summer. The summer cap at the North Pole is made of water ice; the summer cap at the South Pole is made of carbon dioxide ice. During the winter, these caps are covered by a thicker and larger seasonal cap of carbon dioxide ice (not shown). See “Remote Sensing Ices on Mars” Activity for more information.

Next, show students the hydrogen map made by the Mars Gamma Ray Spectrometer (GRS) using either the PowerPoint slide or the overhead transparency. Explain to students that this false-color map was created using gamma rays collected from the surface of Mars. Because hydrogen gives off gamma rays at a unique energy, we can detect the presence of hydrogen buried within the upper few tens of centimeters of the surface of Mars. This hydrogen can be in the form of water ice (H<sub>2</sub>O) or hydrated minerals such as clays. Discuss aspects of the map such as latitude, longitude, and the color scale bar. The colors on the scale bar and map represent different concentrations hydrogen, measured in units of water weight percent (wt% H<sub>2</sub>O). This is based upon the amount of H<sub>2</sub>O that would be required to generate the number of hydrogen gamma rays collected over each area. GRS collects the most gamma rays from high latitude regions, shown in dark blue on the map. Two light blue regions are also present along the equator of the planet with slightly lower water weight percent values. Finally several regions at equatorial and mid-latitudes appear to be dryer with values between 1-7 wt% H<sub>2</sub>O. Explain to students that they will be doing a lab to better understand the physical meaning of water weight percent.

Demonstrate to students the concept of saturated soil by filling a cup half full of soil and another cup with water. Slowly pour the water into the cup with soil, until all the soil is saturated. Pour excess water back into the water cup (be careful not to lose the soil sample). At this point, put the equation for calculating water weight percent on the board for the class.

$$\text{Water weight percent (wt\% H}_2\text{O)} = \frac{\text{Water Weight}}{\text{(Water Weight + Soil Weight)}} \times 100\%$$

#### 2) **Water Weight Percent Lab**



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Explain the purpose of the lab. Each group will determine the water weight percent that a particular soil sample can hold at the point of saturation before becoming oversaturated. In order to accomplish this task, each group will design a lab to determine water weight percent. Students can use the basic lab format provided for this lesson, or one of your choosing. Divide the class into groups of three to four students. Inform the class that each container holds different soil samples, so results will vary between groups. Be sure to remind the students to write their procedure in a systematic format. Give the students about ten minutes to complete their proposed lab and check the procedures before students complete the lab. Provide some guidance to the class, explaining that each group will be given a cup full of dry soil and a cup full of water. Also, explain that each group will have a scale for measuring the mass of the dry soil sample and the mass of the soil samples after water has been added. Decide as a class if the mass of the container should be taken into account; if the mass of the water and soil are significantly greater than the mass of the container, it is okay to get an estimate of water weight percent by disregarding the mass of the container.

It is recommended that students use the information provided above to come up with their own lab procedure. Depending upon classroom circumstances, further guidance may be required. As an option, you may use the sample procedure provided in the Lab Procedure Answer Key as a reference to assist groups that are having trouble writing their own procedures.

Remind students to record their observations as the soil gradually becomes saturated or oversaturated. After the students record their data, discuss their observations. Have a group representative write their soil-moisture percentages on the board. Discuss reasons why some samples had a higher percentage than others.

### 3) **Looking at Earth**

Give students the worksheet regarding soil moistures on Earth. Ask the class to define the difference between icy dirt and dirty ice. Have the students discuss the images seen, as well as the given descriptions, in order to determine the expected water weight percent at each location. After students give their estimated water weight percent, give them the actual percentage estimates and discuss any discrepancies between the estimated values and the actual values. These are provided on the answer key.

Ask the students what they could do to their lab sample in order to better represent the frozen areas shown on the worksheet, namely that they could freeze their samples. Students should discuss what forms when soil is over-saturated and is frozen (snow pack). Show the class the pre-made frozen under-saturated, saturated, and over-saturated samples, and explain that their lab would have looked the same way if it had been frozen. Have each group describe a visual difference between all three samples. Ask if it is possible to represent the over-saturated soil in any other way, or are the soil and ice always separated. Have students brainstorm ways to demonstrate a mixture of soil and frozen water. After the brainstorming has been completed, show the class the crushed ice mixed with soil sample as another way to demonstrate this mixture. Explain that this example may be what is seen on Mars, as well as the possibility of the other frozen samples.



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#### 4) **Bringing the point back to Mars**

Pass out the “Water Estimates on Mars” worksheet and display the GRS map on the overhead or PowerPoint. Review the directions with the class. After the class has finished interpreting the GRS map at the three locations, display the visual map of Mars. Go through each location and ask each group what was written in each box on their worksheet. For location B, there should be some discrepancy between the GRS map and estimated visual appearance.

Have the groups discuss or demonstrate different ways for an over-saturated surface to appear brown on a visual map. Allow each group to present their ideas. Discuss ways we can discover the true nature of the soil below the surface. For example, the upcoming Mars Phoenix Lander mission will be landing in the high latitude region in the northern hemisphere of Mars, where it will be digging into the surface in order to find traces of organic material within the icy soil.

As noted in the introduction, large amounts of hydrogen are found at the high latitude regions of Mars where large amounts of water ice appear to be buried. Water (H<sub>2</sub>O) is composed of two parts hydrogen and one part oxygen and is the most likely molecule to host the hydrogen we see in these low temperature regions surrounding the poles. Notice that even in high latitude regions in the Southern Hemisphere, where carbon dioxide makes up both the permanent summer ice cap (seen in the visible map) and the seasonal winter cap, we see a strong hydrogen signal. Again, this is because there are large amounts of water ice buried throughout this region.

Students may ask about water weight percent values found at equatorial and mid-latitudes. Most of this region has dry soils (1-7 wt% H<sub>2</sub>O). However, two regions appear light blue. It is still not clear if these regions contain buried water ice or if the hydrogen is in the form of hydrated minerals like clays.

#### **ASSESSMENTS**

- Review Water Weight Percent Lab worksheet and Martian Soil worksheet.

#### **EXTENSIONS**

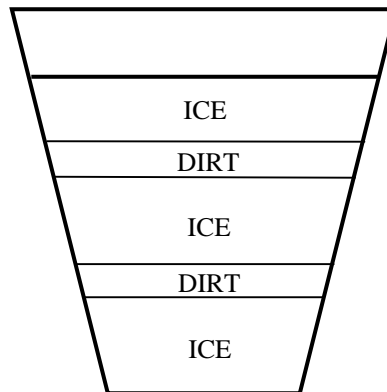
##### **Demonstrating lag deposits**

In order to better demonstrate how lag deposits form, students can do this activity at school or at home (depending on space in the freezer). The experiment can last one to two months. It is best if the students use clear cups. The procedure is as follows:

- 1) Fill a cup less than a quarter full of water, and put it in the freezer.
- 2) When the water in the cup is completely frozen, add enough soil until the frozen water and soil reach a quarter of the cup.
- 3) Add water to the soil until it becomes over-saturated. Put cup into the freezer.
- 4) After the samples in the cup are sufficiently frozen, add another layer of soil. Layers of ice and soil should become apparent.
- 5) Repeat step three.



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- 6) Add one last layer of soil to the top of the frozen sample. DO NOT add any more water. Using a marker, draw a short line indicating the top of each layer of ice and soil. Put the cup back into the freezer.
  - 7) After a week of allowing the cup to remain in the freezer, take the sample out. Observe the layers of ice and dirt. Are they still at their original marks? If not, measure how much they have changed. Which layer or layers is/are causing them to move? Remember to record your data. Mark the new location of the layers. Put the cup back in the freezer.
  - 8) Each week, you will take out the cup and follow step seven. Continue until the two layers of soil finally meet.
  - 9) Consider the following questions: What happened to the ice while it was in the freezer? How long did it take for the two layers of soil to meet? How can this process be related to the North Polar Region on Mars?



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## DIRTY ICE OR ICY DIRT: Water Weight Percent Lab *(Possible Procedure)*

Use this sheet to write up your experiment. Your lab procedure must be approved before you begin the experiment. Note that you will need to use the following equation:

$$\text{Water weight percent (wt\% H}_2\text{O)} = \frac{\text{Water Weight}}{(\text{Water Weight} + \text{Soil Weight})} \times 100\%$$

Lab Objective: The purpose of this experiment is to discover the amount of water that different types of soil can hold when completely saturated. Use the equation for water weight percent above to determine how much water the soil can hold.

Materials: Below is a list of materials for the lab. In the Procedure Section below, describe how you will use these materials to complete the lab objective.

plastic cups (3)  
balance (1)

dry soil sample (1)  
water

pencil or pen  
paper

Procedure: (Provide instructions on how you plan to conduct the experiment.)

1. Weigh empty cup. Record data.
2. Choose one of the four soils supplied by the teacher.
3. Fill one cup half full of selected soil.
4. Weigh cup with soil. Record data.
5. Subtract the weight of the empty cup from the weight of the cup with soil. Record as the soil weight.
6. Fill the other empty cup with water.
7. Slowly pour the water into the cup with the soil, until all the soil is saturated.
8. Pour excess water back into the water cup (be careful not to lose the soil sample).
9. Weigh the cup with the saturated soil. Record data.
10. Subtract the weight of the soil and cup from the weight of the cup with soil and water. Record as the water weight.
11. Using the water weight percent equation, determine the water weight percent of the wet sample. Record data.
12. Clean up.



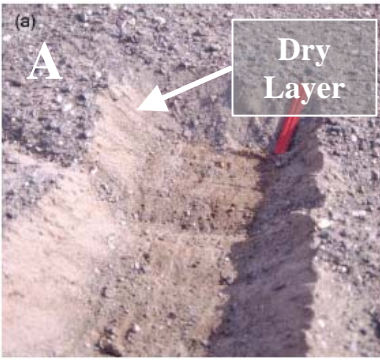
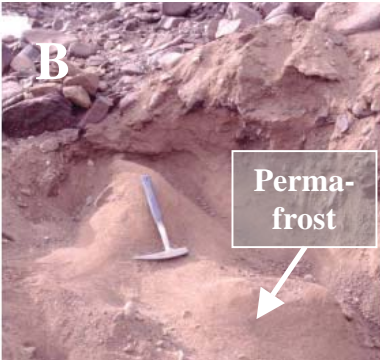

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Observations and Results: (What did you do? What did you find out?)



**DIRTY ICE OR ICY DIRT: Water Estimates on Earth (Answer Key)**

Look at the pictures and descriptions below showing different frozen layers at the surface of Earth. Based on your class results from the water weight percent lab, estimate the water weight percent in the highlighted surface layer. We will discuss the actual water weight percent values as a group.

Figures	Description	Estimated Wt% H <sub>2</sub> O	Actual wt% H <sub>2</sub> O
 <p>Mellon, et al., 2004, Icarus 169, p 337.</p>	<p><u>Under-saturated Dry Layer</u> Cold deserts receive very little precipitation and the soil at the surface tends to be under-saturated. Figure A to the left highlights the top layer of soil in a region in Antarctica. Provide an estimate of the wt% H<sub>2</sub>O in this under-saturated dry layer.</p>	<p><i>Answers will vary.</i></p>	<p>~0-1%</p>
 <p>Mellon, et al., 2004, Icarus 169, p 337.</p>	<p><u>Saturated Permafrost Layer</u> In cold regions, we often found frozen permafrost below the dry layer. This is seen in both Figure A and B. Figure B to the left highlights the permafrost in a region of Antarctica. Permafrost can be fully saturated. Provide an estimate of the wt% H<sub>2</sub>O in the permafrost layer if it was completely saturated.</p>	<p><i>Answers will vary.</i></p>	<p>~10-30%</p>
 <p>Provided by Dante Lauretta, 2003.</p>	<p><u>Over-saturated Ice Sheet</u> Snow packs are areas where the surface is completely over saturated, leaving frozen water above the surface. The picture to the left shows a glacier ice sheet in Antarctica. Provide an estimate of the wt% H<sub>2</sub>O of this ice sheet.</p>	<p><i>Answers will vary.</i></p>	<p>~100%</p>



**DIRTY ICE OR ICY DIRT: Water Estimates on Mars (Answer Key)**

Using the GRS water map of Mars write down the water weight percent in each of the labeled locations. Based upon your lab results and comparisons to environments on Earth, decide whether the soil at each location is more like dry soil, icy dirt, dirty ice, or something else. In the last column, explain your reasoning.

Location	Water Weight Percent	Dry Soil, Dirty Ice, or Icy Dirt	Explanation
<b>A</b>	<i>0-3 Wt% H<sub>2</sub>O</i>	<i>Dry soil</i>	<i>Region A is an under-saturated region with less than 5% water weight percent. There is probably very little to no ice in this region. Some of the water signal could be coming from hydrated minerals found in the soil.</i>
<b>B</b>	<i>20-50 Wt% H<sub>2</sub>O</i>	<i>Dirty ice (buried by soil)</i>	<i>Region B is an over-saturated region with 20-50 water weight percent. The region is more like dirty ice than icy dirt or dry soil. This is based upon the very high water weight percents. In the lab activity, we found that soils typically become saturated around 20 wt% H<sub>2</sub>O.</i>



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### **DIRTY ICE OR ICY DIRT: Summary Questions (Answer Key)**

- 1) Look at a visible map of Mars. Do the regions that you determined to be icy using the gamma ray data appear white or brown in the image?

*For the most part, the three regions labeled in the visible map all appear darker than the white ice caps found at the poles.*

- 2) Brainstorm ideas regarding why icy regions might appear brown in visual images.

*Icy regions may appear darker either because there is a thin layer of dry dirt covering the water ice or because sufficient dirt has been mixed in with the ice to make it appear dark.*

- 3) Why is it helpful to study Mars using more than one remote sensing technique, in this case gamma ray data and visible data?

*Looking at Mars with different types of light gives us a more complete description of the characteristics of the planet.*

