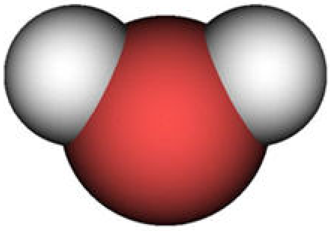
Facilitator Information

(All you need to know about ice and water in our solar system to survive the day)

All About Water

Liquid water is the one substance required by all life as we know it. Water exists in

Water is one of only a few substances that is found naturally in all three states on Earth – solid (ice), liquid, and gas (water vapor). We interact with these states every day; while typically invisible, steam is a common form of water vapor. Clouds are concentrations of water droplets or ice crystals. We are familiar with the solid form of water as ice cubes; hail, sleet, and snowflakes fall from the sky, icicles hang from roofs and trees in winter, glaciers wind their way down mountain valleys, sea ice cover polar seas, and ice caps and ice sheets cover large stretches of continents at the north and south ends of our globe. Water covers just over 70% of Earth's surface. Most of this is in our oceans as salt water (97%), with glaciers and ice caps holding 2.4% of our water in a frozen state. The remaining 0.6% is the freshwater in our rivers and lakes.



It is only on Earth that the three states of water are found together, as far as our exploration of the solar system has discovered.

Water Properties

Water is a tasteless, odorless substance with a neutral pH of 7. It is clear in small volumes but, because it selectively absorbs red light, it is blue in large volumes. The temperature at which pure water changes from a solid to a liquid (melting point) or from a liquid to a solid (freezing point) is 0°C (32°F), and the temperature at which it changes from a liquid to a vapor (boiling point) is 100°C (212°F) at sea level.

Changes in temperature cause water to change state. Increasing the temperature above the melting/freezing point causes ice to melt and change state from solid to liquid (water). Increasing the temperature above the boiling point causes water change from liquid to gas (water vapor).

Unique Properties of Water

While water is well behaved, it does not behave like most other liquids.

Water is a **polar molecule**; its oxygen has a slightly negative charge and its hydrogens – located at "one end" of the molecule - have a slightly positive charge. As opposites attract, water molecules naturally stick together, forming a hydrogen bond. Hydrogen bonds form when the hydrogen atoms of one water molecule are attracted to the oxygen atom of a neighboring molecule. This gives water its high surface tension and causes water to "clump" into drops, rather than spread across a surface.

Water also **dissolves many types of substances**, especially other polar and ionic (made of charged atoms or molecules) substances. This is due in a large part due to its polarized nature and its ability to form hydrogen bonds. When a substance is placed in water, the polarized ends of the water molecules work to break the bonds holding the molecules of the substance together. Positively charged atoms (ions) of the substance are pulled toward the negatively charged oxygens of the water molecules surrounding the substance,

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and negatively charged atoms (ions) are pulled toward the positively charged hydrogens of water molecules. Salts, sugars, acids, alkalis, and gases dissolve in easily in water. While water dissolves a large number of substances, it is not the universal solvent (if it were, you would dissolve when you took a shower … which would be unpleasant at the least).

Water has a **high specific heat capacity**. This is the amount of heat energy required to increase the temperature of a certain volume (usually a gram or a kilogram) of a substance by a certain amount, usually one degree Celsius. Water can absorb a lot of heat before its temperature goes up. This property allows the water in our atmosphere and ocean help to regulate or buffer the rate at which our temperatures change. This is why deserts, with little water vapor in the air, get cold very quickly at night and get hot quickly during the day. This is also why areas very close to oceans or large bodies of water have more gradual temperature shifts day to day or season to season. Water even helps regulate the temperatures of living things; all organisms are made of a significant amount of water by weight!

The **solid form of water – ice – is less dense than the liquid form**. Water is the only known non-metallic substance that expands when it freezes. Water is most dense at 4°C (39°F). When water freezes, its density decreases and it expands approximately 9% by volume. The molecules in the crystal structure of ice have more space between them than the molecules of liquid water. This decreased density allows the solid form of water to float on the liquid form. Such a minor detail has many far-reaching consequences (beyond the tragedy of the Titanic). If solid ice were more dense than water, it would sink, potentially displacing or killing bottom-dwelling aquatic life. In the most extreme conditions, there would be no way to melt the ice in deep lakes and oceans and it would thicken from the bottom to the surface, becoming permanently frozen bodies of ice, and disrupting Earth's water cycle.

Iceberg floating on the ocean.
Image courtesy of the National Science Foundation,
http://photolibrary.usap.gov/index2.htm

Ice in our Solar System

Ice can be found across our solar system from Earth to Mars to the rings of Saturn to the orbiting comets. Recent discoveries suggest it exists at Mercury's poles and future exploration of our Moon encompasses the search for this resource that would be so valuable for future human outposts.

What is Ice?

When you think of ice, you probably think of the ice cubes that you put in drinks, or of snow, or even of the ice on which the polar bears live.

In our solar system there are different types of ice. Planetary scientists consider ice to be substances that we normally find as a liquid or gas at room temperature, but that occur as solids, usually crystalline, in the colder temperatures of our solar system. Water is one of these substances! Ammonia, methane, and carbon dioxide also occur as ices on other planets and moons.

Where is Ice in the Solar System?

A long time ago, in our very own solar system … The processes that formed our solar system four and a half billion years ago helped to distribute the ices. Close to the Sun, it was too hot for water and other ices to condense. Instead rocky materials and metals collected here to form the smaller rocky planets. Farther out, beyond the frost line – that is, somewhere between the asteroid belt and Jupiter – the ices were able to condense in the colder reaches of space, forming the cores of the gas giants and their moons. Beyond the gas giants the Kuiper belt and Oort cloud are host to the leftovers of solar system formation, small icy rocky bodies (yes, including Pluto!), and icy comets.

Terrestrial Planets. If the inner, rocky planets formed in a part of the solar system that was too hot for ices to condense … where did all the ice come from? There are two primary sources, first, the planets themselves, and second, delivery by comets (not unlike having pizza delivered to your home…).

As Earth, Venus, Mars, and Mercury evolved, they released gases from their interiors through volcanic activity. Volcanos on Earth continue to release gases today, including a lot of water vapor. On the early planets, these gases formed the planetary atmospheres. Atmospheres are important for maintaining relatively constant surface temperatures. On planets or moons without atmospheres that are close to the Sun, the surfaces in sunlight get very hot and the surfaces in darkness (night side) get very cold.

On *some* of the terrestrial planets, water vapor in the early atmospheres eventually condensed and precipitated to form oceans once the planetary surfaces cooled. Each planet has a different history that influences whether or not it has ice.

Mercury. Mercury's relatively small size did not provide sufficient gravitational attraction to "hold" an atmosphere. Because it was small, it cooled quickly, so volcanic processes stopped early in its history and did not replenish its atmosphere. In addition, Mercury is the closest to the Sun. Solar wind weathered away its atmosphere and continues to heat its surface to temperatures that are far too hot for water to condense or for ice to exist … except, possibly, in a few special places (foreshadowing!).

Venus. Venus has a very dense atmosphere that contains ~97% carbon dioxide. Carbon dioxide is a green house gas, a gas that can absorb solar radiation in the thermal infrared range of the spectrum. This thick blanket of gas traps the Sun's radiation and heats the planet's surface to a whopping 467°C (872°F). The surface of Venus is the hottest in the solar system – hotter even than Mercury, which is closer to the Sun! Venus is too hot to have any type of ice on it.

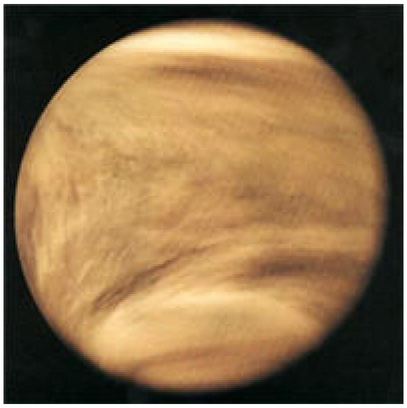

Image courtesy of NASA, http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-venus.html.

Earth. Earth's atmosphere, like any planetary atmosphere, helps to moderate our temperatures so that the Sun's radiation does not cause the surface to get too hot on the daytime side or plunge to temperatures well below freezing on the nighttime side. The small amounts of greenhouse gases, such as water vapor and carbon dioxide, help to warm Earth even more, making it habitable. Earth's average temperature is about 15°C (59°F), but it ranges from -89°C (-128°F) to 58°C (136°F).

Not surprising, the ice on Earth is water ice because we have an abundance of water. Water ice is found where the temperatures are below the freezing point of water and there is enough precipitation for snow or ice crystals to fall or there is water that can freeze. Permanent ice is found on Earth's high mountains and in its polar regions, and sometimes in protected areas such as caves. During the winter months, seasonal temperatures get cold enough to allow snow to temporarily accumulate farther from the poles.

Snowflake. Image courtesy of SnowCrystals.com, http://www.its.caltech.edu/~atomic/snowcrystals/photos/photos.htm.

Antarctic mountain range. Image courtesy of the National Science Foundation, http://photolibrary.usap.gov/index2.htm.

Glacier meets ocean. Image courtesy of the National Science Foundation, http://photolibrary.usap.gov/index2.htm.

The freezing point of carbon dioxide is -78°C (-108°F); pure ammonia's freezing point is -77°C (-107°F). These ices could exist in the coldest places on Earth, but the substances do not exist naturally in sufficient amounts.

Mars. Early Mars had a climate that was warmer and wetter than today; its atmosphere was thicker and water flowed across the surface. Mars may even have had oceans. As the interior of Mars cooled, volcanism declined and the atmosphere of Mars thinned. Today's atmosphere is made of 95% carbon dioxide, 3% nitrogen, and small amounts of other gases, including water, oxygen, and methane. The atmospheric pressure on the surface of Mars is about 1/100 that of Earth's atmospheric pressure at sea level. Because of the thin atmosphere and Mars' distance from the Sun, Mars is cold. Its temperatures range from −87°C to −5°C, well under the freezing point of water and also cold enough to freeze carbon dioxide.

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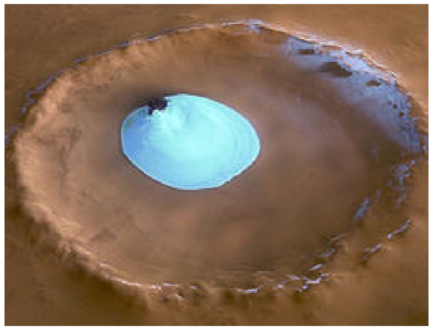
Because of the low atmospheric pressures, liquid water at the surface of Mars would evaporate into water vapor. So what happened to all that water that used to be on the surface of Mars? Some did evaporate into space. But much is frozen under the surface and in the polar ice caps. Mars has water ice!



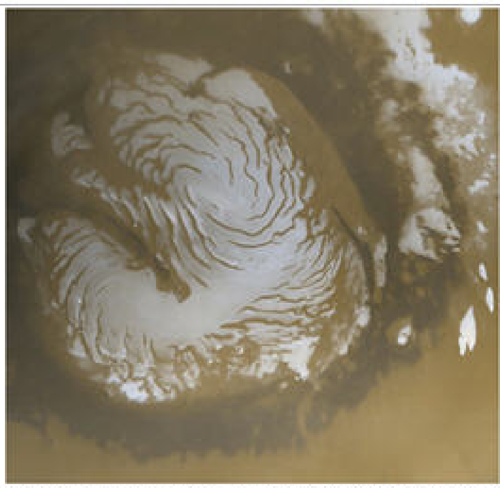
Water ice in a 35-kilometer-wide crater in the northern hemisphere of Mars. The light dusting of ice on the crater edges is carbon-dioxide ice.

Image courtesy of the European Space Agency (ESA/DLR/FU Berlin (G. Neukum), http://www.esa.int/esaMI/Mars_Express/ SEMGKA808BE_1.html

But Mars also has another type of ice – carbon dioxide ice! In the winter the carbon dioxide in the atmosphere condenses and falls to the ground as carbon dioxide ice. In the summer, much of this changes from the solid form back into gas (sublimates).

Image courtesy of NASA.

Mars has ice caps at both its poles. The north pole ice cap is about 1100 kilometers (700 miles) across - larger than the state of Texas (!). The southern ice cap is about 1/10 this size. Both ice caps are made mostly of water ice, but the southern ice cap has a permanent cover of carbon dioxide ice. The ice caps grow each winter as carbon dioxide ice is added to them, and decrease each summer as the carbon dioxide sublimates.



Northern ice cap on Mars. Much of the ice cap is water ice, with a thin layer of carbon-dioxide ice on the surface. Image courtesy of NASA, http://ai.jpl.nasa.gov/public/home/chien/spring-agu-images/MLS/Mars_Ice_Cap.jpg.

Southern ice cap of Mars. This ice cap has two layers. A top layer of carbon dioxide ice, about 8 meters (27 feet) thick, lies over a thick layer of water ice. Image courtesy of NASA.

Like Earth, Mars' climate has fluctuated through geologic time, sometimes getting warmer and sometimes getting colder. During colder times, its ice caps expanded and glaciers extended farther across the Martian landscape.

The Curious Cases of the Moon … and Mercury. Our Moon has no atmosphere; as it spins on its axis, its surface experiences temperatures ranging from 225°F (107°C) in sunlight to –243°F (–153°C) in the dark. Ice and water cannot exist under these conditions; they would evaporate. Why then, is NASA exploring the Moon's surface to see if water ice exists?

The Moon's poles have areas of permanent light and permanent darkness. Sunlight reaches the north and south polar regions at low angles of incidence. Because the Moon's axis of spin is tilted at a very small 1.5 degrees to its orbit around the Sun, this low angle of incidence does not change during the year (as it does on Earth, causing seasons). Deep craters at the poles never receive sunlight. They are permanently shadowed and permanently cold! These are the cold-storage pits of the lunar surface. They are cold enough to trap volatiles — elements that evaporate readily at standard temperature and pressure – like water.

Radar data collected by the Clementine spacecraft suggest that water ice, perhaps mixed with regolith, exists at the lunar south pole. Spectrometers onboard the Lunar Prospector spacecraft detected hydrogen — one component of water — at the lunar poles. Based on the presence and distribution of the hydrogen, scientists hypothesize the presence of extensive water ice at the poles. Several spacecraft will provide more definitive data about the presence of water ice. NASA's Lunar Reconnaissance Orbiter (LRO) and India's Chandrayaan-1 spacecraft carry radar instruments to map the extent and distribution of materials at the poles in far greater detail than previous missions. NASA's Lunar Crater Observation and Sensing Satellite (LCROSS) mission will help confirm the presence of water ice by impacting the lunar surface in a permanently shadowed crater. The resulting plume will be analyzed for water ice and vapor and other materials by instruments on the LCROSS shepherding spacecraft and the LRO, and by telescopes on Earth. If there is ice at the lunar poles, there are still many questions about how it got there, its composition, how fast it accumulates, and how much regolith is mixed with it.

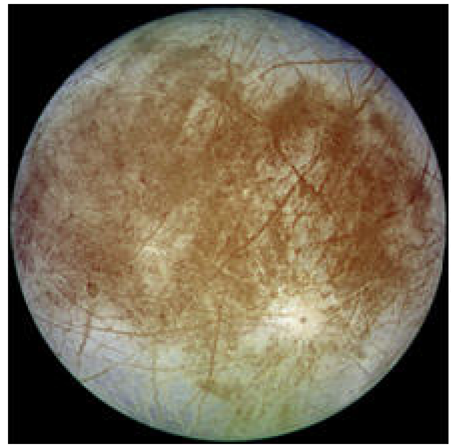
Water is a valuable resource for future human exploration and habitation on the Moon. The presence of water will reduce the cost of transporting water to the Moon (at $10,000 per pound!). Beyond the need for drinking water, it can be separated into its two components — hydrogen and oxygen — and used to make propellant for spaceflight. The oxygen can also be used for the production of breathable air.

Where did this ice on the Moon come from? Comets! Comets striking the surface of the Moon delivered water ice that became trapped in the permanently shadowed craters. This process is not unique to the Moon. Comet impacts occur across our solar system, delivering water ice and other substances to all of the planets and moons.

Mercury is too hot to have any form of ice … or is it? Mercury also lacks an atmosphere, and it is very close to the Sun. Like the Moon, however, Mercury's axis is tilted only a small amount; at 0.1 degrees, it is tilted less even than the Moon. And like the Moon, Mercury has deep craters at its poles that are permanently shadowed – and permanently cold. These cold dark craters could trap water and store it as ice. In the coming years

NASA's MESSENGER mission will provide more information about whether or not water ice exists at Mercury's poles.

The Gas Giants and Their Moons
Based on the scientific models of how our solar system formed, it is no surprise that the moons of the gas giants are rich in ice!



Jupiter's Moons. Europa's crust of water ice floats on top of a salt water ocean. The crust may be many miles (kilometers) thick and its surface is very smooth. It does not have many craters, suggesting that the surface is relatively young and active; the processes that cover or remove craters are continuing to happen.

The icy shell of Europa is one of the smoothest surfaces in the solar system. The reddish streaks may be from salts such as magnesium sulfate, that were left behind by evaporating water.

Image from NASA, http://photojournal.jpl.nasa.gov/catalog/PIA00502.

Europa is far from the Sun and its surface temperature is a chilling −160°C (−260°F) at the equator and -220°C (−370°F) at its poles. At these temperatures the water ice is very hard and rock-like. The ocean under the ice blanket is kept heated by the constant "tug" on Europa by Jupiter and the other moons as Europa orbits Jupiter. Europa gets pulled and stretched in different directions by the gravitational attraction of the planet and its moons, generating heat (tidal heating). The presence of liquid water could mean that life is supported in the sea of Europa.

Surface of Europa showing thick plates of ice that float on the ocean underneath. Image courtesy of NASA, http://photojournal.jpl.nasa.gov/jpeg/PIA01127.jpg.

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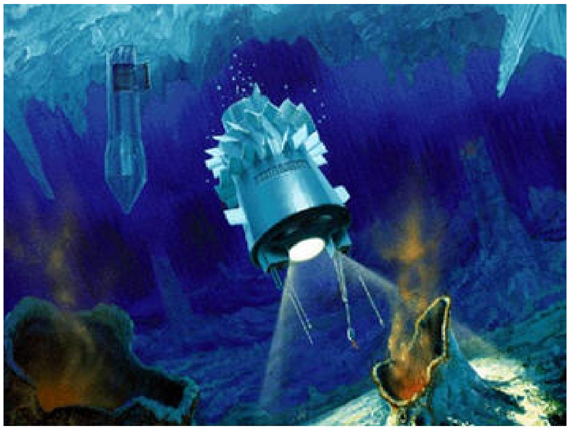
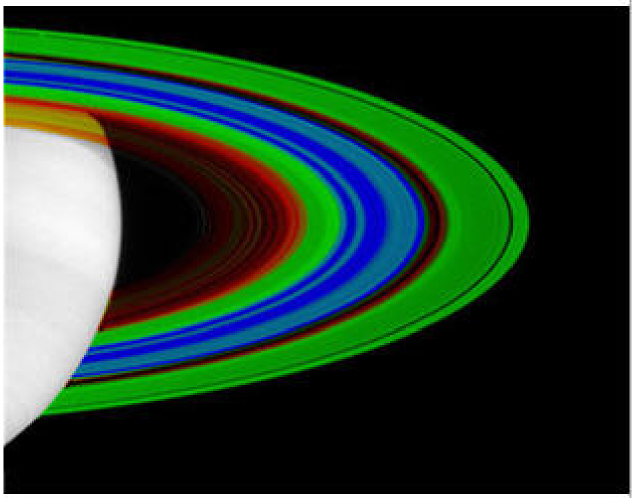
Artist's drawing of what probes, sent aboard spacecraft missions to Europa, may find at the sea floor of the moon's salty ocean. Image courtesy of NASA, http://sealevel2.jpl.nasa.gov/jr_oceanographer/oceanographer-carsey.html



Jupiter's moons Ganymede and Callisto also are mixture of rock and water ice. Callisto is composed mostly of rock and water ice, although other ices like ammonia ice and carbon dioxide ice may be present.

Image of Callisto courtesy of NASA http://photojournal.jpl.nasa.gov/catalog/PIA03456.

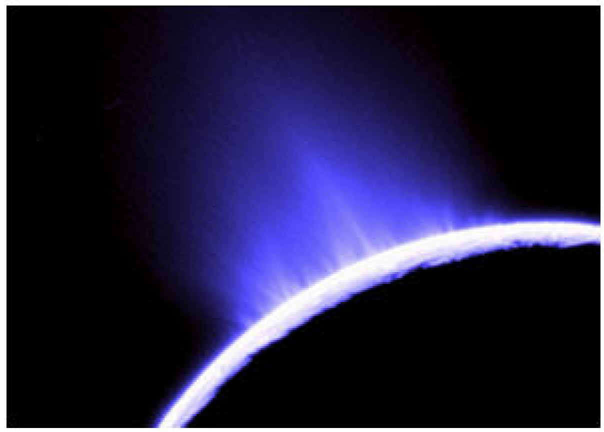
Saturn's Rings and Moons. Saturn's rings are one of the most remarkable features in the solar system. They are 250,000 kilometers (155,000 miles) or more in diameter and less than one kilometer (half a mile) thick! The rings are composed of particles ranging from the size of dust specks to large boulders, and are more than 90% water ice!

	
Saturn's rings. Image courtesy of NASA, http://saturn.jpl.nasa.gov/photos/imagedetails/index.cfm?imageId=2998.	Temperatures of Saturn's rings taken by Cassini-Huygens instruments. Red colors are -163°C, green is about -183°C and blue is -203°C. Image courtesy of NASA, http://www.nasa.gov/mission_pages/cassini/media/cassini-090204_prt.htm

Saturn has over 60 moons. Most are small; over half are less than 20 kilometers (12 miles) in diameter. Most of the satellites appear to have lots of water ice, with varying amounts of rocky material; Mimas and Tethys are composed almost completely of water ice, Iaeptus and Rhea appear to be about 25% rocky material, and Dione, Enceladus, and Titan are about 50% rocky material. All of these bodies are heavily cratered. Most have surface temperatures less than -170°C (-274°F), well below the freezing point of water and other ices. Water ice at the surfaces of these moons is rock-hard.

Enceladus caught the attention of scientists and the world with its spectacular geysers. The Cassini spacecraft flew through a plume and sampled water vapor and ice particles. Scientists suggest that the water collects in heated, pressurized chambers under Enceladus' surface and periodically erupts at the surface - an icy geyser. The material vented by Enceladus is what makes up Saturn's E Ring!

The icy surface of Enceladus. False-color image courtesy of NASA, http://saturn.jpl.nasa.gov/photos/imagedetails/index.cfm?imageId=3344.



Plumes of water vapor and ice particles are jetted above the surface of Enceladus. Image courtesy of NASA, http://apod.nasa.gov/apod/ap071013.html.

Comets

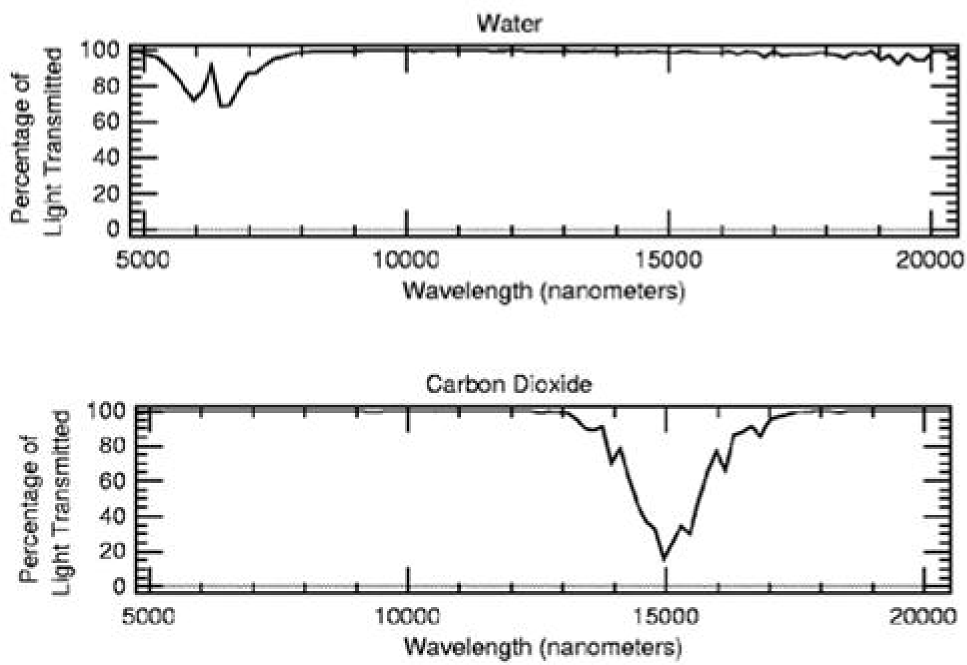
Comets have been called the "dirty snowballs" of our solar system! Every comet is made of the same basic ingredients — ice and dust. However, comets vary in how much of the ice is water ice and how much is ice made of other substances, including methane, ammonia, carbon dioxide, carbon monoxide, sulfur, and hydrogen sulfide. Comets also vary in the different types of trace elements and hydrocarbons that are present.

Comet Hyakutake. Image by Jim Martin, Huntsville AL, Courtesy of NASA, http://apod.nasa.gov/apod/ap960326.html.

For over 4.6 billion years, since the formation of our solar system, comets have been colliding with planets and moons and asteroids, delivering their water ice to these bodies. Comets may be the source for water ice on the Moon and Mercury, and they certainly have added water to other celestial bodies, including Earth.

How Do We Look for Ice in the Solar System?
The discussion about where water ice might be in our solar system shares some of the ways that scientists are testing for its presence. If scientists cannot go to a planet to explore or send a lander that will return samples, they can examine the surface using a variety of detectors onboard spacecraft or on Earth-based telescopes.

One of the primary ways of detecting water is to analyze the spectrum of light reflected from a planetary surface. Different materials reflect and absorb different – and characteristic – wavelengths of light. Some of these wavelengths are visible to our eyes (red, green, yellow, blue, purple) and some are invisible to us (for example, infrared or ultraviolet wavelengths). Water has a characteristic spectral fingerprint, especially in the infrared. Spectra can be collected by spectrometers onboard orbiting spacecraft or by telescopes viewing the planet or planetary body from Earth.



Comparisons of the spectra of water and carbon dioxide. Every substance has a unique spectral "fingerprint." Scientists can compare the spectra from the surface of a planet to spectra of known substances to determine what materials occur on the planet. Image from http://www.pbs.org/wgbh/nova/teachers/activities/3113_origins_04.html.

Scientists also use radio waves to detect ice. Different surfaces reflect radio waves in different ways. Ice, and soils mixed with ice, have characteristic signatures. Other instruments onboard spacecraft, such as gamma ray spectrometers, can detect the abundance of hydrogen (and other elements), which is a component of water molecules. The presence of hydrogen may be interpreted to indicate the existence of water on a planet.

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