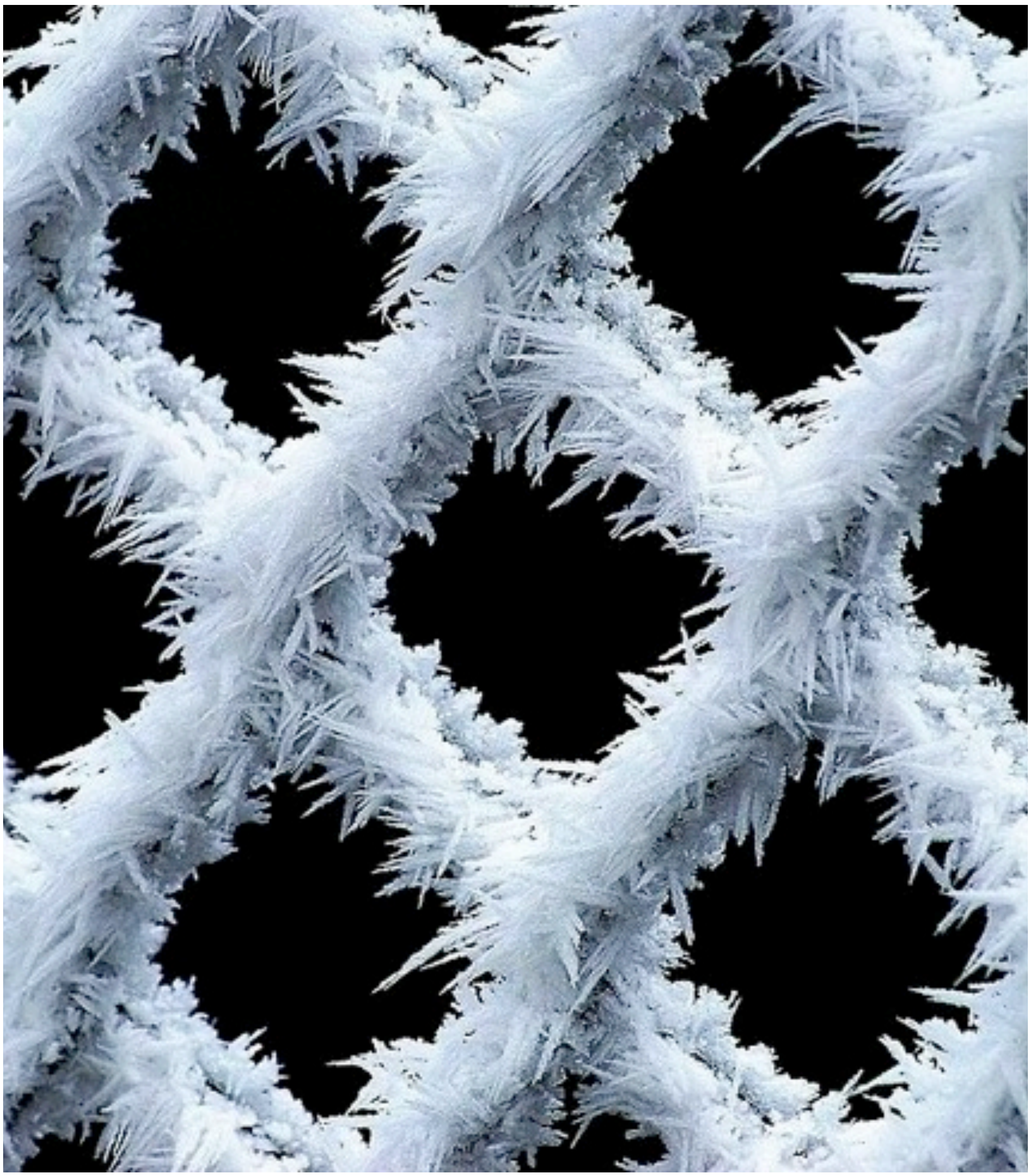
Frozen Water

Module 8 • i2P • H2O Tour



"Smooth ice is Paradise for those who dance with expertise"

- Friedrich Nietzsche

THE MAGIC OF FROZEN WATER

Snow, ice, hail, frost. It colors our world in so many ways. Those who live where the temperature falls below zero bemoan the piles of snow to be shoveled in deep winter, while celebrating the intricate magic of each unique snowflake. Those who live where it is always hot make artificial ice to refrigerate food and cool their drinks. Snowy city streets are dressed with salt and gravel to prevent cars from skidding, while, at huge expense, we create the smoothest and slipperiest artificial ice surfaces for skaters and hockey players. All of this activity involves one simple molecule, water; water that is frozen.

Frozen water is a miraculous substance. It is mass produced commercially, is used for sport in both natural and artificial forms, contains the majority of the worlds fresh water resources, disrupts transportation, breaks apart mountains, causes the electrification of thunderclouds, cools our drinks, and much, much more. What accounts for the ability of this simple molecule, when frozen, to do all these remarkable things?

PHASES OF MATTER

To understand the unique properties of frozen water it is best to start with a brief description of the phases of matter. There are three principle phases of matter in the world: gas, liquid and solid. The three phases of water - gas (water vapor), liquid (water) and solid (ice and snow) - are all commonly found on Earth and have important functions in the world's water cycle (see module: The Water Cycle).

On a simplistic level, the different phases of matter are accounted for by the arrangement of molecules which, when progressively bound more closely together, transform the substance from gas to liquid to solid. This process of changing a substance from a gas to a liquid to a solid requires the removal of energy (usually in the form of heat) from the substance. That is why cooling water causes it to change from a liquid to a solid. Conversely adding heat (energy) to a substance can transform it from a solid to

> Did You Know?
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> All known liquids,with the exception of Helium, have a solid form. Helium is the only Substance that remains a liquid at Absolute zero (-273.15 degrees Celsius)

liquid, or liquid to gas. A simple example is that of boiling water (adding heat) which converts it from a liquid to a gas. Indeed the freezing of water and the melting of ice are two of the most common and dramatic examples of phase transitions in nature.

An Unusual Solid

Most solid forms of a substance are more compact and dense than liquid or gas forms of the substance. As explained above, when energy is removed from a liquid the molecules generally group closer together as they form a solid. It would seem logical then that ice, a solid, is more dense and hence heavier than its liquid form. If so it would follow that ice should sink in a glass of water. But it doesn't of course. How can something more dense (a solid) float in something less dense (a liquid)?

The reason that ice floats in a glass of water is because water is an exception to this rule, its solid form is less dense than its liquid state. Unlike virtually all other substances which shrink in size as they are cooled to a solid state, water expands. The expansion of water as it freezes produces very powerful forces, enough to not only rupture frozen water pipes and bottles of water left in the freezer but to break apart massive chunks a rock from the sides of mountains as moisture built-up in cracks during the day, freezes and expands in sub zero overnight temperatures.

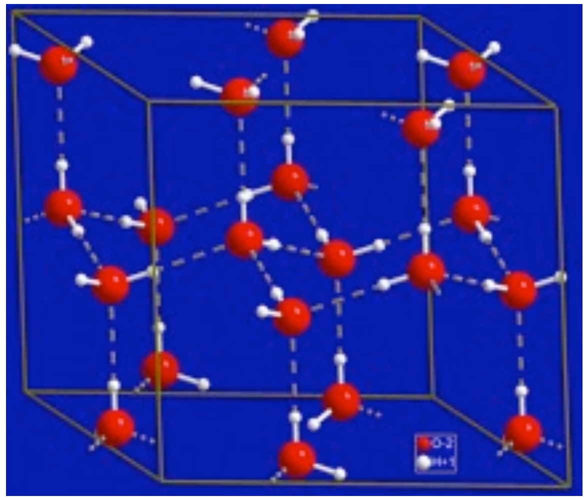
> Did You Know?
> That when frozen, pure water expands by 9%.

Structure of Ice

Because of the unique hexagonal or six-sided bonds that form between the oxygen atoms in water molecules, water expands as it freezes. All naturally occurring ice crystals are defined by this hexagonal structure, and is reflected in the shape of snowflakes which are invariably six-sided (see: Structure of Ice). As ice forms hexagonal bonds are formed that pull water molecules together and trap air between them, more air than is found dissolved in liquid water. This accounts for the increased volume and decreased density of ice compared to liquid water.

Although all naturally occurring ice crystals have the classic six-sided structure, there are in fact up to 12 known distinct crystalline structures of ice, most off which can only be created under artificial conditions of pressure and temperature (see: ice crystals). No

other substance in the world has this variety of molecular structures.



Ice Flow

One of the most remarkable properties of ice is that is can flow. This property is seen in glaciers which flow downhill, carving great troughs in the land and changing the topography (see: Into the Pass). Once again ice is unique in this manner as most solids do not have the capacity to flow. Imagine if wood and concrete and steel all flowed? If this were so, however slowly, aging buildings would gradually flow to the ground.

The reason ice can flow is because the bonds in ice, when placed under significant pressure, can be deformed. Thus the great weight of a glacier deforms the ice below it, pushing it downhill, similar to (but much slower) than a river flowing downstream. The deformation of the ice bonds that allows glacial flow to occur requires a significant amount of pressure, roughly equivalent to the weight of ice that is fifty meters (160 feet) thick. Thus it is only the bottom layer of a glacier - that below fifty meters - that flows, with the ice on top being pulled along, and cracking and fissuring as the glacier moves downhill and around bends. These surface cracks are called crevasses.

Slip Sliding Away

It might not be evident upon first inspection that ice can flow but everyone knows that ice is slippery. Whether on skates, skis or on a toboggan, ice and snow allow one to slide along with ease. Once again ice is unique among solids in this manner; there are no commonly occurring solid materials that are as slippery as ice. Have you ever attempted to skate or ski on on rock, or wood, or grass or asphalt? Yet,curiously, a definitive explanation for why ice is slippery still eludes scientists.

There are three basic theories explaining why ice is slippery. They share one common conclusion that a film of liquid water forms or exists on the surface of

> **Did You Know?**
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> Ice is needed to cause lightening.
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> Lightening is produced in thunderstorms when liquid and ice particles above the freezing level collide, and build up large electrical fields in the clouds. Once these electric fields become large enough, a giant "spark" occurs between them, causing a lightening charge (see: cause of lightening)

> **Did You Know?**
> If all the ice presently existing on earth melted, the sea level would rise over 70 m.

the ice causing it to be 'unstable' and hence slippery but the manner in which this film of water comes to be on the surface of the ice is where the theories differ.

The oldest theory is that pressure, exerted by a skate blade for instance, causes compression of the molecules on the surface of the ice. Since water is more dense than ice the compression of the surface layer of solid ice causes it to briefly turn to water, allowing the skater to slide along on a cushion of liquid. The theory, although still widely quoted in textbooks (see: Why ice is slippery), has been disproved because it fails to explain why objects that do not exert much pressure, like a hockey puck, slide easily. Nor does it explain why ice continues to be slippery at lower temperatures when this film of water is not expected to form with pressure.

> **Did You Know?**
> A cube of frozen alcohol — which has a freezing temperature of minus 173 degrees Fahrenheit

The second theory is that friction from the material sliding over ice generates enough heat to melt a thin layer of water on the surface of the ice. A good example of this process would be the frictional heat generated by a wooden ski as it passes over snow allowing a layer of melt water to occur upon which the ski can slide. However it is felt that this effect does not explain why someone who is standing still on the ice (no friction) still finds it slippery.

So a third and more recent theory has been developed to explain why ice is slippery. Understanding that ice gains it strength from the hexagonal structure of the bonds that form between molecules, it has been hypothesized that those water molecules on the outside of a piece of ice are not surrounded by other water molecules and consequently cannot be fixed by the classic hexagon bonds. This destabilizes the molecules on the outer surface of a piece of ice rendering them movable, and hence slippery.

Although these three theories all have some merit in explaining the slippery nature of ice, the definitive explanation of this fantastic property remains elusive.

If Ice Were More Dense Than Water

The fact that ice floats on water has a profound impact on the world's ecosystem. In the winter northern lakes and polar oceans freeze over. Ice forms on top of the water becoming an insulating layer that buffers the water below from the cold winter conditions, protecting the water dwelling animals. The ice surface above serves as a platform upon which a host of animals hunt and travel, among them polar bears and penguins. Ice by nature reflects the energy of the sun. Water, in contrast absorbs a significant proportion of the suns energy. If ice did not cover the northern and southern waters in there respective winters there would be a significant increase in the cumulative solar energy absorbed by the Earth, accelerating global warming.

Indeed the entire state of the world would be very different if the solid phase of water behaved like most other solids. Lakes would freeze from the bottom up, killing all life within them. More solar energy would be absorbed by the world's waters, accelerating the warming of the atmosphere. Animals such as polar bears and penguins would be deprived of their traditional habitat.

Baikal Crust

Not only would the state of the world be different if ice were heavier than water, but so would the progress of the i2P expedition across Lake Baikal. Rather than trekking Ray and Kevin would find themselves swimming. Fortunately ice is less dense than water and in winter forms a welcome crust over the deep waters of the lake, that will hold the i2P team as they journey across.

Did You Know?

There are remarkable fish that live in polar waters that are below zero. In order to prevent their tissue and bodily fluid from freezing they possess an antifreeze protein.