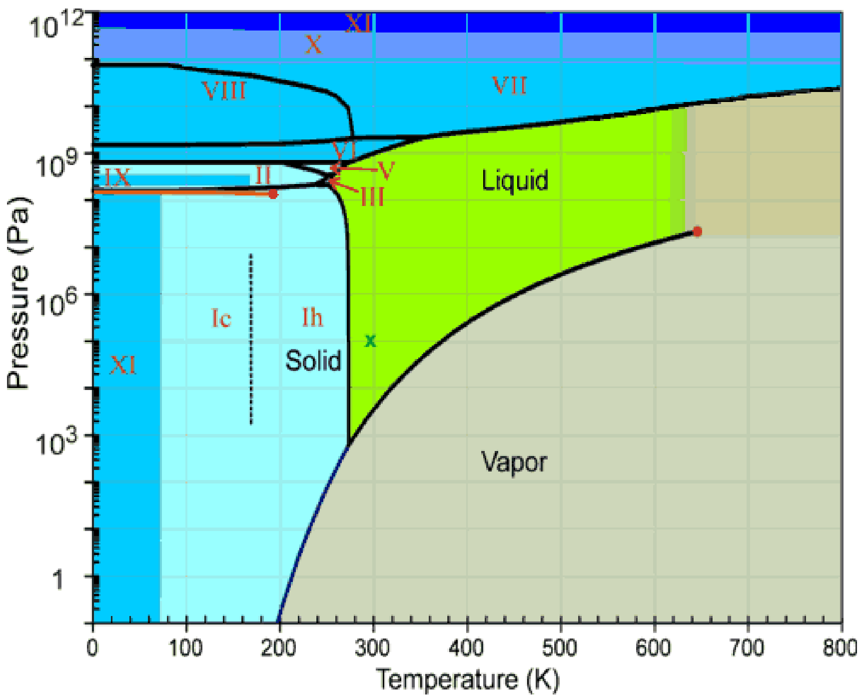
The Phase Diagram of Water

A phase diagram shows the preferred physical states of matter at different temperatures and pressure. At typical room temperatures and pressure (shown as an 'x' below) water is a liquid, but it becomes solid (*i.e.* ice) if its temperature is lowered below 273 K and gaseous (*i.e.* steam) if its temperature is raised above 373 K, at the same pressure. Each line gives the conditions when two phases coexist but a change in temperature or pressure may cause the phases to abruptly change from one to the other. Where three lines join, there is a 'triple point' when three phases coexist but may abruptly and totally change into each other given a change in temperature or pressure. Four lines cannot meet at a single point. A 'critical point' is where the properties of two phases become indistinguishable from each other. The phase diagram of water is complex,[g] having a number of triple points and one or possibly two critical points.



The boundaries shown for ice-ten (X) and the high pressure ice-eleven(XI) and the boundary between supercritical water and ice-seven (VII) (see [691]) are still to be established.

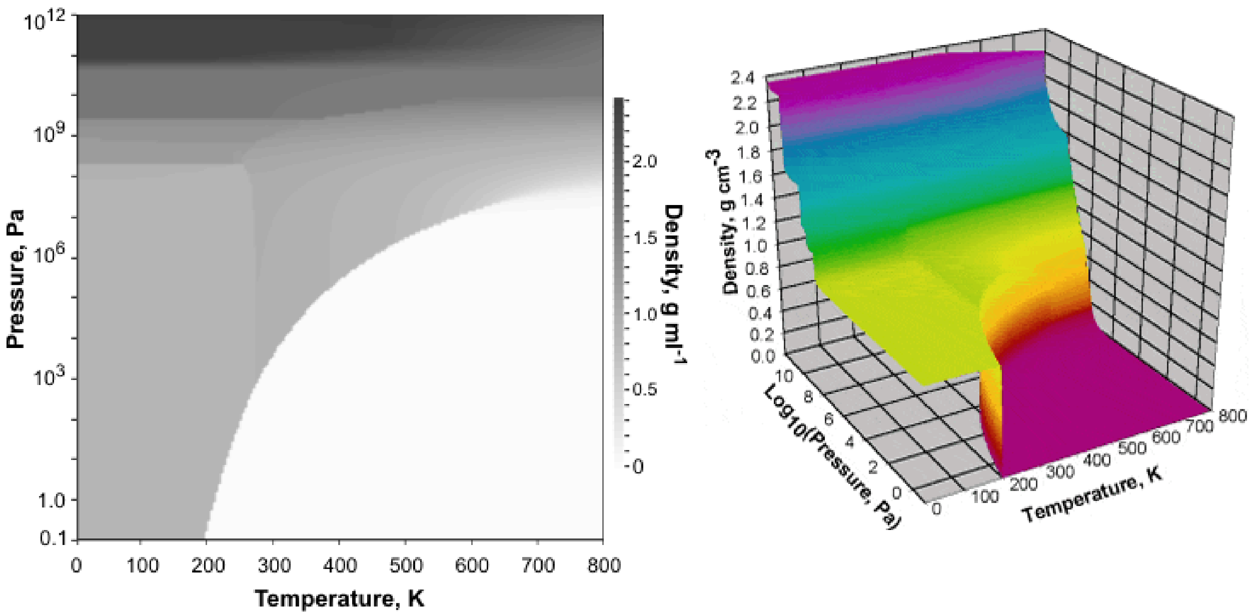
All the solid phases of ice involve the water molecules being hydrogen bonded to four neighboring water molecules. In all cases the two hydrogen atoms are equivalent, with the water molecules retaining their symmetry, and they all obey the 'ice' rules: two hydrogen atoms near each oxygen, one hydrogen atom on each O····O bond. The H-O-H angle in the ice phases is expected to be a little less than the tetrahedral angle (109.47°), at about 107°.

Triple points			MPa	°C	Ref.	D_2O [711]
liquid	gas	Ih	0.000611657	0.010	536	661 Pa, 3.82°C [70]
liquid	gas	XI	0	-201.0	711	0 MPa, -197°C
liquid	Ih	III	207.5	-22.0	537	220 MPa, -18.8°C
Ih	II	III	212.9	-34.7	537	225 MPa, -31.0°C
II	III	V	344.3	-24.3	537	347 MPa, -21.5°C
liquid	III	V	346.3	-17.0	537	348 MPa. -14.5°C
II	V	VI	~620	~-55	539	
liquid	V	VI	625.9	0.16	537	629 MPa, 2.4°C
VI	VII	VIII	2,100	~5	8	1950 MPa, ~0°C
liquid	VI	VII	2,200	81.6	8	2060 MPa, 78°C
VII	VIII	X	62,000	-173	538	
liquid	VII	X	43,000	>700	612	

Both the critical points are shown as red circles in the phase diagram, above. Beyond the critical point in the liquid-vapor space (towards the top right, above), water is supercritical existing as small but liquid-like hydrogen-bonded clusters dispersed within a gas-like phase [456], where physical properties, such as gas-like or liquid-like behavior, vary in response to changing density. The properties of supercritical water are very different from ambient water. For example, supercritical water is a very poor solvent for electrolytes, but excellent for non-polar molecules, due to its low dielectric constant and poor hydrogen bonding. The physical properties of water close to the critical point (near-critical) are particularly strongly affected [677].

The critical point and the orange line in the ice-one phase space refer to the low-density (LDA) and high-density (HDA) forms of amorphous water (ice) [16]. Although generally accepted, the existence of this second, if metastable, critical point is impossible to prove at the present time and is disputed by some [200, 618, 628]. The transition between LDA and HDA is due to the increased entropy and van der Waals contacts in HDA compensating for the reduced strength of its hydrogen bonding. The high-pressure phase lines of ice-ten (X) and ice-eleven (XI) [81] are still subject to experimental verification. Two different forms of ice-eleven have been described by different research groups: the high-pressure form (also known as ice-thirteen) involves hydrogen atoms equally-spaced between the oxygen atoms [84] (like ice-ten) whereas the lower pressure low temperature form utilizes the incorporation of hydroxide defect doping (and interstitial K^+ ions) to order the hydrogen bonding of ice Ih [207], that otherwise occurs too slowly. Another ice-ten has been described, being the proton ordered form of ice-six (VI) occurring below about 110 K. Only hexagonal ice-one (Ih), ice-three (III), ice-five (V), ice-six (VI) and ice-seven (VII) can be in equilibrium with liquid water, whereas all the others ices, including ice-two (II, [273]), are not stable in its presence under any conditions of temperature and pressure. Ice-two, ice-eight (VIII), ice-nine (IX), ice-ten [80] and ice-eleven (both) all possess (ice-nine incompletely) ordered hydrogen-bonding whereas in the other ices the hydrogen-bonding is disordered even down to 0 K, where reachable. Ice-four (IV) and ice-twelve (XII) [82] are both metastable within the ice-five phase space. Cubic ice (Ic) is metastable with respect to hexagonal ice (Ih). It is worth emphasizing that liquid water is stable throughout its phase space above. Kurt Vonnegut's highly entertaining story concerning an (imaginary) ice-nine, which was capable of crystallizing all the water in the world [83], fortunately has no scientific basis (see also I_E) as ice-nine, in reality, is a proton ordered form of ice-three, only exists at very low temperatures and high pressures and cannot exist alongside liquid water under any conditions. Ice Ih may be metastable with respect to empty clathrate structures of lower density under negative pressure conditions (*i.e.* stretched) at very low temperatures [520].

As pressure increases, the ice phases become denser. They achieve this by initially bending bonds, forming tighter ring or helical networks, and finally including greater amounts of network inter-penetration. This is particularly evident when comparing ice-five with the metastable ices (ice-four and ice-twelve) that may exist in its phase space.



The liquid-vapor density data for the graphs above were obtained from the IAPWS-95 equations [540].

Other phase diagrams for water are presented elswewhere [681].

Ice polymorph	Density, g cm^{-3} [a]	Protons[f]	Crystal[h]	Symmetry	Dielectric constant, ε_S [i]	Notes
Hexagonal ice, Ih	0.92	disordered	Hexagonal	one C_6	97.5	
Cubic ice, Ic	0.92	disordered	Cubic	four C_3		
LDA [b]	0.94	disordered	Non-crystalline			As prepared, may be mixtures of several types
HDA [c]	1.17	disordered	Non-crystalline			As prepared, may be mixtures of several types
VHDA [d]	1.25	disordered	Non-crystalline			
II, Ice-two	1.17	ordered	Rhombohedral	one C_3	3.66	
III, Ice-three	1.14	disordered	Tetragonal	one C_4	117	protons may be partially ordered
IV, Ice-four	1.27	disordered	Rhombohedral	one C_3		metastable in ice V phase space
V, Ice-five	1.23	disordered	Monoclinic	one C_2	144	protons may be partially ordered
VI, Ice-six	1.31	disordered	Tetragonal[e]	one C_4	193	protons can be partly ordered
VII, Ice-seven	1.50	disordered	Cubic[e]	four C_3	150	two interpenetrating ice Ic frameworks
VIII, Ice-eight	1.46	ordered	Tetragonal[e]	one C_4	4	low temperature form of ice VII
IX, Ice-nine	1.16	ordered	Tetragonal	one C_4	3.74	low temperature form of ice III
X, Ice-ten	2.51	symmetric	Cubic[e]	four C_3		symmetric proton form of ice VII
XI, Ice-eleven	0.92	ordered	Orthorhombic	three C_2		low temperature form of ice Ih
XI, Ice-eleven	>2.51	symmetric	Hexagonal[e]	distorted		Found in simulations only
XII, Ice-twelve	1.29	disordered	Tetragonal	one C_4		metastable in ice V phase space

Ice polymorph	Molecular environments	Small ring size (s)	Helix	Approximate O-O-O angles, °	Ring penetration hole size
Hexagonal	1	6	None	All 109.47±0.16	None

ice, Ih					
Cubic ice, Ic	1	6	None	109.47	None
LDA [b]	3+	5, 6	None	mainly 108, 109 and 111	None
HDA [c]	6+	5, 6	None	broad range	None
VHDA [d]	6+	5, 6	None	broad range	None [747]
II, Ice-two	2 (1:1)	6	None	80,100,107,118,124,128; 86,87,114,116,128,130	None
III, Ice-three	2 (1:2)	5, 7	4—fold	(1) 91,95,112,112,125,125 (2) 98,98,102,106,114,135	None
IV, Ice-four	2 (1:3)	6	None	(1) 92,92,92,124,124,124 (3) 88,90,113,119,123,128	some 6
V, Ice-five	4 (1:2:2:2)	4, 5, 6, 8	None	(1) 82,82,102,131,131,131 (2) 88,91,109,114,118,128 (3) 85,91,101,103,130,135 (4) 84,93,95,123,125,126	8 (1 bond)
VI, Ice-six	2 (1:2)	4, 8	None	(1) 77,77,128,128,128,128 (2) 78,89,89,128,128,128	8 (2 bond)
VII, Ice-seven	1	6	None	109.47	every 6
VIII, Ice-eight	1	6	None	109.47	every 6
IX, Ice-nine	2 (1:2)	5, 7	4—fold	(1) 91,95,112,112,125,125 (2) 98,98,102,106,114,135	None
X, Ice-ten	1	6	None	109.47	every 6
XI, Ice-eleven	1	6	None	109.47	None
XI, Ice-eleven	undetermined	6	None	undetermined	every 6
XII, Ice-twelve	2 (1:2)	7, 8	5—fold	(1) 107,107,107,107,115,115 (2) 67,83,93,106,117,132	None

[a] density at atmospheric pressure. [Back]

[b] Low-density amorphous ice (LDA). The structural data in the Table is given assuming LDA has the structure of ES. [Back]

[c] High-density amorphous ice (HDA). The structural data in the Table is given assuming HDA has the structure of crushed CS. [Back]

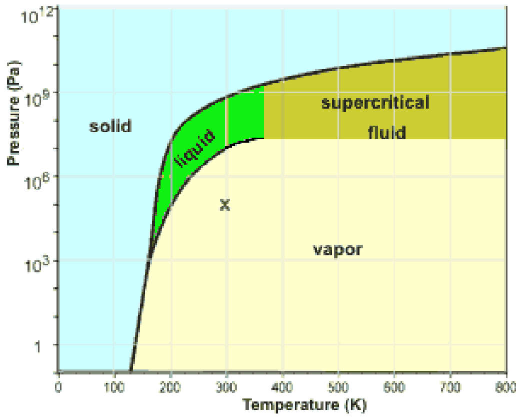
[d] Very high-density amorphous ice (VHDA). The structural data in the Table assumes no hydrogen bond rearrangements from LDA or HDA. [Back]

[e] Structure consists of two interpenetrating frameworks. [Back]

[f] Although primarily ordered or disordered, ordered arrangements of hydrogen bonding may not be perfect and disordered arrangements of hydrogen bonding are not totally random as there are correlated and non-bonded preferential effects. [Back]

[g] If water behaved more typically as a low molecular weight material, its phase diagram may have looked rather like this:

[Back]



[h] Crystal cell parameters have been collated [711]. [Back]

[i] Dielectric constants fall into two categories dependent on whether the hydrogen bonds are ordered (low values) or disordered (high values). [Back]

Forty-one Anomalies of Water [1]

It has often been stated (*e.g.* [127]) that life depends on the anomalous properties of water. In particular, the large heat capacity, high thermal conductivity and high water content in organisms contribute to thermal regulation and prevent local temperature fluctuations. The high latent heat of evaporation gives resistance to dehydration and considerable evaporative cooling. Water is an excellent solvent due to its polarity, high dielectric constant and small size, particularly for polar and ionic compounds and salts.[2] It has unique hydration properties towards biological macromolecules (particularly proteins and nucleic acids) that determine their three-dimensional structures, and hence their functions, in solution. This hydration forms gels that can reversibly undergo the gel-sol phase transitions that underlie many cellular mechanisms [351]. Water ionizes and allows easy proton exchange between molecules, so contributing to the richness of the ionic interactions in biology.

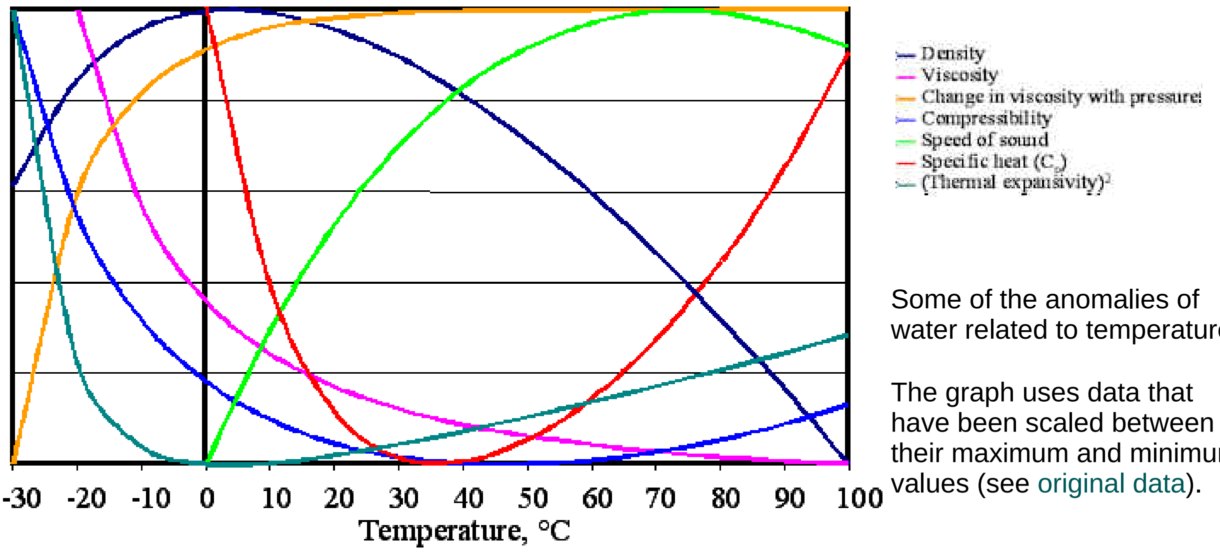
At 4°C water expands on heating or cooling. This density maximum together with the low ice density results in (i) the necessity that all of a body of water (not just its surface) is close to 0°C before any freezing can occur, (ii) the freezing of rivers, lakes and oceans is from the top down, so insulating the water from further freezing, reflecting back sunlight into space and allowing rapid thawing, and (iii) density driven thermal convection causing seasonal mixing in deeper temperate waters. The large heat capacity of the oceans and seas allows them to act as heat reservoirs such that sea temperatures vary only a third as much as land temperatures and so moderate our climate (*e.g.* the Gulf stream carries tropical warmth to northwestern Europe). The compressibility of water reduces the sea level by about 40 m giving us 5% more land. [65]

Notable amongst the anomalies of water are the opposite properties of hot and cold water, with the anomalous behavior more accentuated at low temperatures. As cold liquid water is heated it shrinks, it becomes less easy to compress, its refractive index increases, the speed of sound within it increases, gasses become less soluble and it is easier to heat and conducts heat better. In contrast as hot liquid water is heated it expands, it becomes easier to compress, its refractive index reduces, the speed of sound within it decreases, gasses become more soluble and it is harder to heat and a poorer conductor of heat. With increasing pressure, cold water molecules move faster but hot water molecules move slower. Hot water freezes faster than cold water and ice melts when compressed except at high pressures when liquid water freezes when compressed. No other material is commonly found as solid, liquid and gas.[3]

The anomalies

1. Water has unusually high melting point. [explanation]
2. Water has unusually high boiling point. [explanation]
3. Water has unusually high critical point. [explanation]
4. Water has unusually high surface tension and can bounce. [explanation]
5. Water has unusually high viscosity. [explanation]
6. Water has unusually high heat of vaporization. [explanation]
7. Water shrinks on melting. [explanation]
8. Water has a high density that increases on heating (up to 3.984°C). [explanation]
9. The number of nearest neighbors increases on melting. [explanation]
10. The number of nearest neighbors increases with temperature. [explanation]
11. Pressure reduces its melting point (13.35 MPa gives a melting point of -1°C) [explanation]
12. Pressure reduces the temperature of maximum density. [explanation]
13. D_2O and T_2O differ from H_2O in their physical properties much more than might be expected from their increased mass; *e.g.* they have increasing temperatures of maximum density (11.185°C and 13.4°C respectively). [explanation]
14. Water shows an unusually large viscosity increase but diffusion decrease as the temperature is lowered. [explanation]
15. Water's viscosity decreases with pressure (at temperatures below 33°C). [explanation]
16. Water has unusually low compressibility. [explanation]
17. The compressibility drops as temperature increases down to a minimum at about 46.5°C. Below this temperature, water is easier to compress as the temperature is lowered. [explanation]

18. Water has a low coefficient of expansion (thermal expansivity). [explanation]
19. Water's thermal expansivity reduces increasingly (becoming negative) at low temperatures. [explanation]
20. The speed of sound increases with temperature (up to a maximum at 73°C). [explanation]
21. Water has over twice the specific heat capacity of ice or steam. [explanation]
22. The specific heat capacity (C_P and C_V) is unusually high. [explanation]
23. Specific heat capacity; C_P has a minimum and C_V has maximum. [explanation]
24. NMR spin-lattice relaxation is very small at low temperatures. [explanation]
25. Solutes have varying effects on properties such as density and viscosity. [explanation]
26. None of its solutions even approach thermodynamic ideality; even D_2O in H_2O is not ideal. [explanation]
27. X-ray diffraction shows an unusually detailed structure. [explanation]
28. Supercooled water has two phases and a second critical point at about -91°C. [explanation]
29. Liquid water may be supercooled, in tiny droplets, down to about -70°C. It may also be produced from glassy amorphous ice between -123°C and - 149°C [74] and may coexist with cubic ice up to -63°C [137]. [explanation]
30. Solid water exists in a wider variety of stable (and metastable) crystal and amorphous structures than other materials. [explanation]
31. Hot water may freeze faster than cold water; the Mpemba effect. [explanation]
32. The refractive index of water has a maximum value at just below 0°C. [explanation]
33. The solubilities of non-polar gases in water decrease with temperature to a minimum and then rise. [explanation]
34. At low temperatures, the self-diffusion of water increases as the density and pressure increase. [explanation]
35. The thermal conductivity of water is high and rises to a maximum at about 130°C. [explanation]
36. Proton and hydroxide ion mobilities are anomalously fast in an electric field [explanation]
37. The heat of fusion of water with temperature exhibits a maximum at -17°C [15]. [explanation]
38. The dielectric constant is high and behaves anomalously with temperature. [explanation]
39. Under high pressure water molecules move further away from each other with increasing pressure. [explanation]
40. The electrical conductivity of water rises to a maximum at about 230°C and then falls. [explanation]
41. Warm water vibrates longer than cold water. [explanation]



Some of the anomalies of water related to temperature.

The graph uses data that have been scaled between their maximum and minimum values (see original data).

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[1] Whether or not the properties of water are seen to be anomalous depends upon which materials water is to be compared and the interpretation of 'anomalous'. For example, it could well be argued that water possesses exactly those properties that one might deduce from its structure (see *e.g.* [402]). Comparisons between water, liquid sodium, argon and benzene appear to Franks [112] to indicate several of the properties given above as not being anomalous. However these materials are perhaps not the most typical of liquids. My list gives the unusual properties generally understood to make liquid water (and in one case ice) stand out from 'typical' liquids (or in one case solids). See [242] for a review concentrating on the non-anomalous properties of water; *i.e.* those that are the 'same' as for other

liquids. [Back]

2 It is therefore difficult to obtain really pure water (*e.g.* < 5 ppb impurities). For a review of aqueous solubility prediction see [744]. Note that ice, in contrast, is a very poor solvent and this may be made use of when purifying water (*e.g.* degassing) using successive freeze-thaw cycles. [Back]

3 The temperature range of 'hot' and 'cold' water varies in these examples; see the individual entries for details. [Back]

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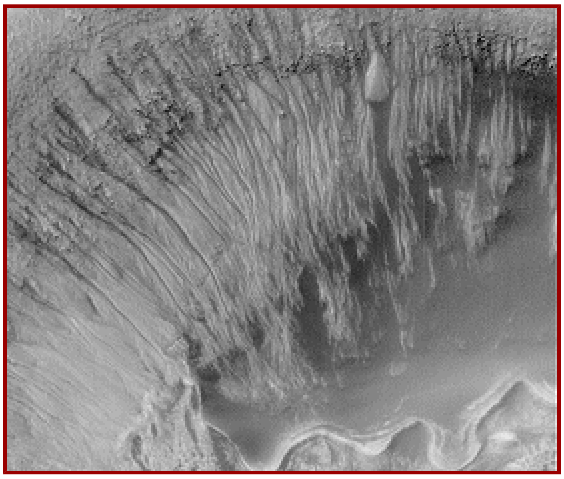
Making a Splash on Mars

On a planet that's colder than Antarctica and where water boils at ten degrees above freezing, how could liquid water ever exist? Scientists say a dash of salt might help.



June 29, 2000 -- Last week when scientists revealed dramatic new pictures of flood-like gullies on Mars, the big surprise wasn't that the Red Planet might harbor water. Researchers have known for years that water exists there. There are trace quantities of water *vapor* in Mars' atmosphere and substantial amounts of water *ice* at the martian poles. There may even be enough frozen water beneath Mars' surface to fill a large ocean if melted. What was amazing is that water may be present as a *liquid* very near the planet's surface and occasionally on top of the surface when underground deposits burst forth for a brief flash flood.

"We have conditions on Mars that seem to forbid liquid water very close to the surface," said Michael Carr of the USGS at the June 22, 2000, NASA press conference. "At high latitudes [where the gullies are located], the temperatures are 70 to 100 degrees centigrade below freezing. It's incredibly cold. We expect the ground to be frozen 3 to 6 km deep."

Above: Martian gullies in Newton Crater. Scientists hypothesize that liquid water burst out from underground, eroded the gullies, and pooled at the bottom of this crater as it froze and evaporated. If so, life-sustaining ice and water might exist even today below the Martian surface -- water that could potentially support a human mission to Mars. [more from GSFC]

The low temperature of Mars conspires with the planet's thin atmosphere (it's 100 times thinner than Earth's) to make water possible in only two forms: solid ice and gaseous vapor. A cup of liquid water transported Star Trek-style to the surface of Mars would instantly freeze or boil (depending on the local combination of temperature and pressure). Researchers think that the water which carved the martian gullies probably boiled explosively soon after it erupted from underground.

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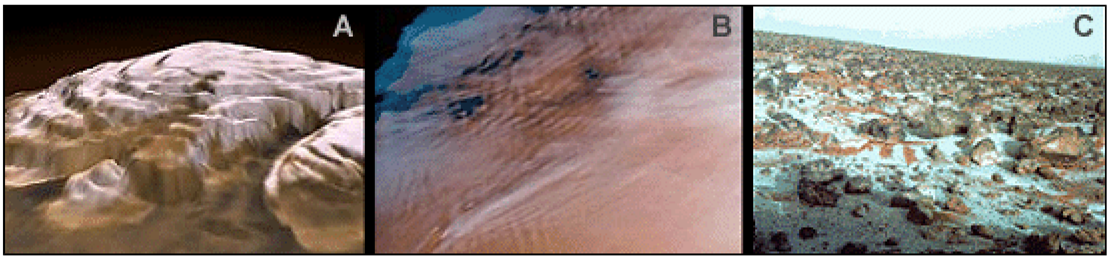
"The air pressure is so low on Mars that even in the most favorable spots, where the pressure is higher than average, liquid water is restricted to the range 0 to +10 °C," says Bob Haberle of the NASA/Ames Research Center. "Fresh water on Mars begins to boil at 10 °C. Here on Earth we can have water anywhere between 0 and 100 °C -- that range is reduced by a factor of ten on Mars."

If the thought of boiling water at 10 degrees °C seems bizarre, simply consult a high-altitude cookbook for a reality check. On mountaintops where the air pressure is low, water boils at a lower temperature than it does at sea level. (At 9000 ft a 'three-minute' boiled egg takes about five minutes to fully cook!) Mars simply takes the principles of high-altitude cooking to an extreme.



Above: Water on Mars. **A**: A 3D view of the Martian north pole created from Mars Global Surveyor laser altimeter data. The cap is composed mainly of solid water ice. [more from GSFC] **B**: Wispy clouds of water ice hover over the Kasai Vallis region of Mars. [more from GSFC] **C**: Ground frost (or snow) consisting of water ice at the Viking 2 landing site on Utopia Planitia.

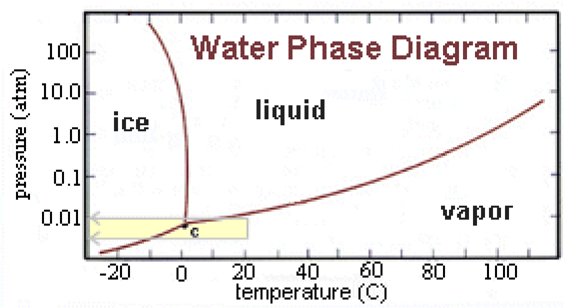
Although any liquid water exposed to Mars' low-pressure atmosphere is likely to boil, vapor is not the most important repository of martian H_2O. If all the vapor in the present-day atmosphere rained down on one spot, it would barely fill a small pond. On the other hand, the martian poles contain lots of water in the form of a solid. The north polar cap, composed primarily of water ice, is 1200 km across and up to 3 km thick in some places. The water volume there is about 4% of the Earth's south polar ice sheet. Even more water ice is thought lie deep underground.

Parents and Educators: Please visit Thursday's Classroom for lesson plans and activities related to this story.

So, the big question is not whether water exists on Mars -- it does -- but rather is there liquid water despite the planet being so cold? The prospects for life on Mars, both human and martian, hinge on the answer.

"First of all, you have to remember that the average atmospheric pressure on Mars is very close to the triple point of water," explains Richard Hoover, an astrobiologist at the Marshall Space Flight Center. "You only have to increase the pressure a little bit to make liquid water possible."

The 'triple point' is the combination of pressure (6.1 millibars) and temperature (0.01 °C) at which water can exist simultaneously in all three states: a solid, a liquid and a gas (see the 'phase diagram' below). On Earth, our experience with the triple point is usually limited to ice skating. The temperature of ice on a skating rink is just a fraction of a degree from the triple point. A little bit of pressure on the solid ice can cause it to transform to a liquid. The weight of a skater applied to the ice along the blade of the skate therefore creates a thin layer of liquid water that lubricates the blade and makes gliding possible.



On Mars the globally-averaged surface pressure of the planet's atmosphere is only slightly less than 6.1 millibars.

"That's the average," says Haberle, "so some places will have pressures that are higher than 6.1 millibars and others will be lower. If we look at sites on Mars where the pressure is a bit higher, that's where water can theoretically exist as a liquid."

Above: A phase diagram of water. The 'triple point' (labeled "C" in the diagram) is the temperature and pressure where all three types of water can exist at once. In the diagram, note that liquid water cannot exist below 6.1 millibars. This fact is significant because the atmospheric pressure at the martian surface hovers just below that value. Any water that might form on a warm afternoon from melting water would quickly disappear in the desiccated martian atmosphere.

Haberle has developed a sophisticated climate model for Mars based in part on Mars Global Surveyor topography data. A simple version of the model is the basis for daily martian weather forecasts at the Ames Mars Today web site.

"I used the model to look for regions that meet the minimum requirements for liquid water -- above the triple point and below the boiling point," explained Haberle. "According to the model, the highest surface pressure, 12.4 millibars, occurs at the bottom of the Hellas Basin (a low-lying area created by an ancient asteroid strike). The problem is that the boiling temperature there is only +10 °C. It can't get very hot or the water will boil away."

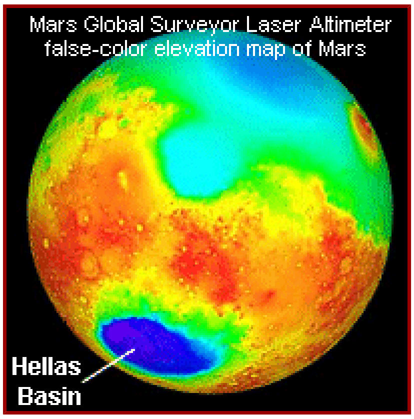
The Triple Point of Water

A Martian Coincidence?

The atmospheric surface pressure on Mars is remarkably close to the triple point pressure 6.1 millibars. Is that a coincidence? Some scientists think not. If the global pressure were higher and liquid water was widespread on Mars's surface, CO2 in the atmosphere would dissolve in water and react with silicate rocks, trapping atmospheric carbon dioxide in carbonate minerals. This process would thin out the atmosphere until the pressure dropped below the triple point. Thus, the martian atmosphere could be self-limiting in this respect. [more information]

Evaporation of water in contact with Mars' dry atmosphere is also a problem, says Haberle. "Liquid water can be stable against freezing and stable against boiling, but unstable with respect to evaporation. The situation is analogous to Earth's oceans. Liquid water on the surface does not freeze ... or boil, yet it can evaporate if the atmosphere is not saturated with water vapor. [more information]

"There are 5 five distinct regions where we might sometimes find surface water: in the Amazonis, Chryse and Elysium Planitia, in the Hellas Basin and the Argyre Basin. Together they comprise about 30% of the planet's surface. That's not to say that liquid water really does exist in those places, just that it could."



Conditions would be favorable for liquid water only during the martian day. The temperature falls precipitously at night, so any liquid would re-freeze. At the Viking lander sites, for example, instruments registered temperatures as high as -17 C in the air and +27 °C in the soil on sunlit summer days. After sunset, thermometer readings plunged back to -60 °C or below. [click for more information about martian temperatures]

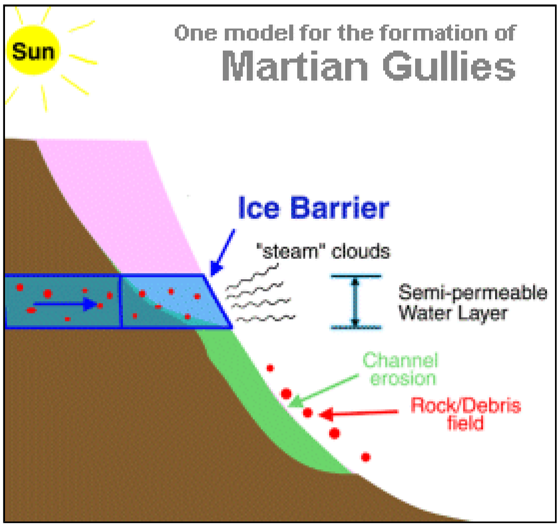
Left: The massive Hellas impact basin in the southern hemisphere of Mars is nearly 9 kilometers deep and 2,100 kilometers across. The air pressure at the bottom of the basin is about twice the global average. In this false-color image based on measurements from the Mars Global Surveyor laser altimeter, red and white colors denote high elevations and blue denotes low.

Follow the Salt...

"One thing we have to be careful of is our everyday experience that water always freezes at zero degrees," noted Hoover. "It doesn't. Water containing dissolved salts freezes at a significantly lower temperature. Don Juan Pond in Antarctica is a good example. It's a high salinity pond with liquid water at temperatures as low as -24 °C."

"Salts have the potential to significantly lower the freezing point of water," agrees Steve Clifford of the Lunar and Planetary Institute. "Indeed, there are some combinations of salts that can lower the freezing point by as much as 60 °C. However, thermodynamic and chemical stability arguments (arising from work by Benton Clark) suggest that, on Mars, the most potent freezing point-depressing brines are likely to be based on NaCl (common table salt)."

A recent analysis of a Martian meteorite by Arizona State University scientists suggests that ancient martian oceans -- if they existed -- contained a mix of salts similar to those in Earth's oceans today. That wasn't the first clue that Mars was salty, though. In 1976 the two Viking landers analyzed martian soil and found that it probably contained 10 to 20 percent salts. Martian rocks, like those on Earth, react to form salt and clay minerals when exposed to water. On our planet this process gives rise to a variety of brines in the western salt lakes of North America. The detailed chemistry of the brines depends on the composition of local rocks.



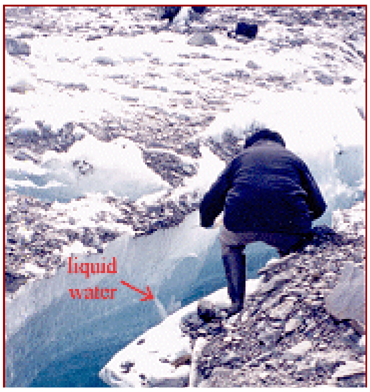
Above: This cartoon, which is based on a figure presented by Dr. Ken Edgett of Malin Space Science Systems at the June 22nd NASA press conference, shows one way that gullies might form on Mars. Underground liquid water behind a barrier of ice erupts for a short-lived flash flood, creating the characteristic channels and aprons of martian gullies. The ice plugs are formed on the shadowed slopes of craters and ravines. Salts dissolved in the water behind the plug could help it stay liquid. [more from JPL]

... and go with the flow

Another way to help keep water liquid -- on Mars or Earth -- is to keep it moving.

"If you know a hard freeze is coming where you live, what's the first thing you do?" asks Hoover. "You turn your faucets on a little to let water trickle out. This way your pipes won't freeze."

The same principle applies on Mars where salty water could be moving through subterranean aquifers. "Ice is a crystal," explains Hoover, "and it's harder to form crystals when the water is flowing."



Last year, Hoover visited the Matanuska Glacier in Alaska to search for cold-loving microorganisms living in and around the ice.

"I chose the Matanuska Glacier to visit because it's accessible and has dark rock in contact with ice," says Hoover. "The sun shining on the rock causes the ice to melt. There are pools of liquid water where microorganisms grow in abundance. There is something very interesting and exciting about this picture of me taking samples from the edge of a moulin (a water-carved crevasse). Most of what we see is ice and the air temperature is below freezing, yet there is liquid water pouring out of the glacier. How is that possible? The water had broken free further back up the glacier where sunlit rocks melted the ice. Then it flowed beneath the ice until it broke through a hole in the wall of the ice. Everything the liquid water came in contact with was freezing, yet the moving water did not freeze.

"I have also seen liquid water running from snow melting on dark rocks heated by sunlight in Antarctica, even though the air temperature was below -20 °C."

Above: Sampling ice from a moulin in the tongue of Alaska's Matanuska glacier. Orange moss can be seen growing on broken rock debris on ice ledge [larger image]. (Photos Courtesy Richard B. Hoover)

There are many places on Earth where liquid water and ice co-exist in sub-zero conditions, says Hoover. The most famous example is Lake Vostok, an expanse of water roughly the size of lake Ontario lying 4 km beneath the Antarctic ice sheet. The ice sheet acts as a blanket, shielding the lake from Mars-like temperatures at the surface.

Will explorers one day discover oases like Lake Vostok beneath icy terrain on Mars? No one knows. But instead of "Follow the Water," the mantra of future colonists on the red planet might well be "Follow the Salt."

Stay tuned to Science@NASA for continuing series of stories about Water on Mars.

JPL manages the Mars Global Surveyor Mission for NASA's Office of Space Science, Washington, DC. Malin Space Science Systems built and operates the camera system. JPL is a division of the California Institute of Technology, Pasadena, CA. JPL's industrial partner is Lockheed Martin Astronautics, Denver, CO, which developed and operates the spacecraft.

Web Links

Mars Global Surveyor Home Page - from NASA/JPL

Malin Space Science Systems -- MSSS operates and processes data from instruments on planetary missions under contract to the National Aeronautics and Space Administration (NASA).

Science@NASA Stories about Mars:

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