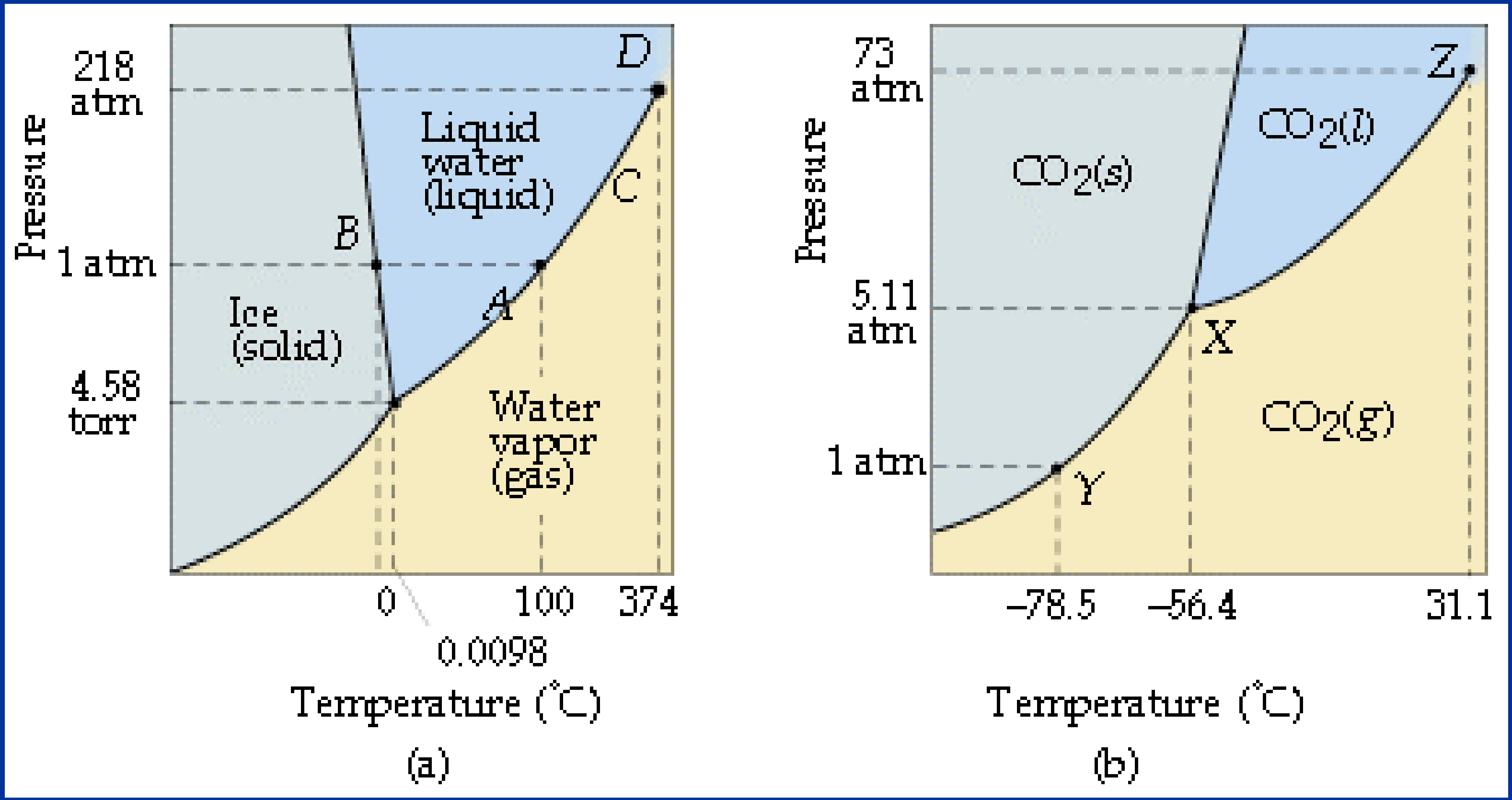
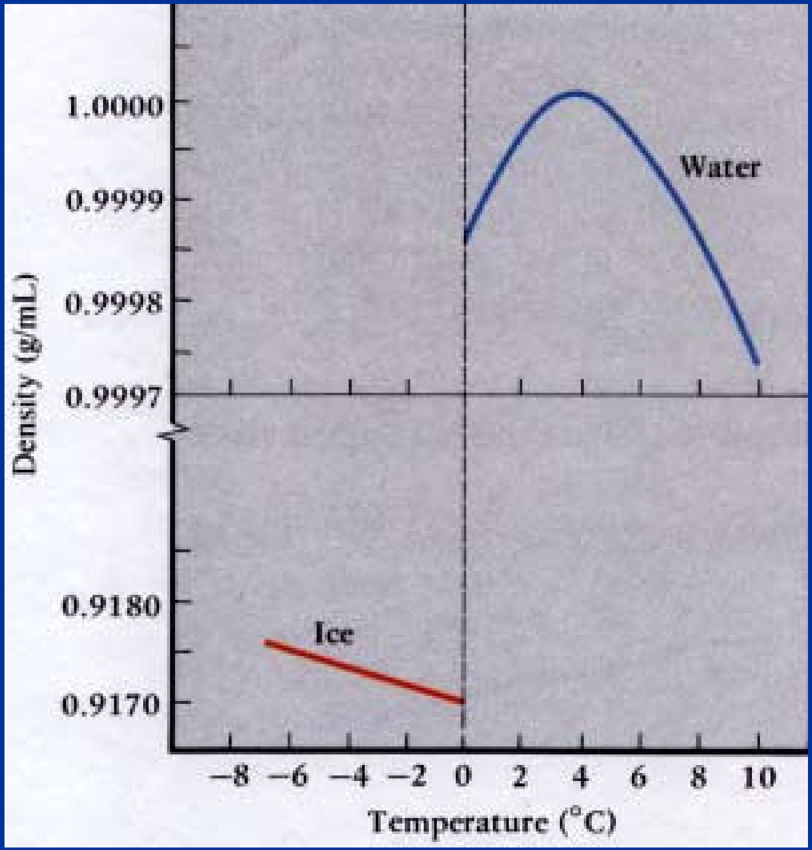
Phase diagram of water



Note: for H_2O melting point decreases with increasing pressure, for CO_2 melting point increases with increasing pressure.



Density (g/mL)
1.0000
0.9999
0.9998
0.9997
0.9180
0.9170
Water
Ice
−8 −6 −4 −2 0 2 4 6 8 10
Temperature (°C)

WATER

Covers ~ 70% of the earth’s surface

Life on earth depends on water

Water is a “universal” solvent

Easily polluted; hard to purify.

Yet, water is an anomaly

“Water is the most remarkable substance. However, water is often perceived to be pretty ordinary. We wash in water, fish in water, swim in water, drink water and cook with water”

“We are about two-thirds water and require water to live. Life as we know it could not have evolved without water and dies without it. Droughts cause famines and floods cause death and disease.

“Because of its clear importance, water is the most studied material on Earth. It comes as a surprise, therefore, to find that it is so poorly understood, not only by people in general, but also by scientists working with it everyday.”

http://www.sbu.ac.uk/water/index.html
Martin Chapin , Professor of Applied Science
South Bank University
London SE1 0AA

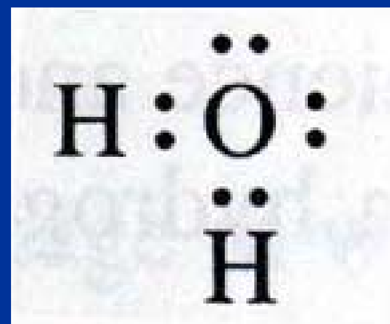
“the long term existence of our watery planet as a place hospitable for the evolution of life involves a considerable amount of good luck.”

http://witcombe.sbc.edu/water/physicsearth.html

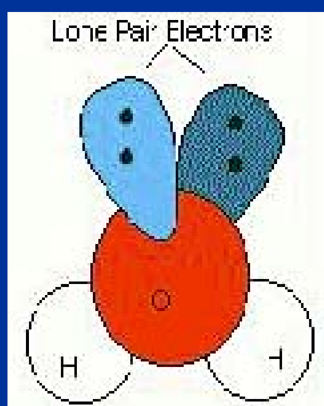
“Today, more than a billion people have to walk over a mile every day for their drinking water, 80 percent of all diseases result directly from drinking polluted water, and many believe future wars will be fought over fresh water,” *Water: The Drop of Life*, PBS, 2000

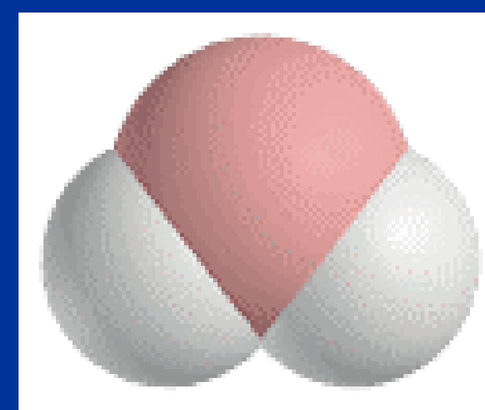
Why is water unique?

Shape of water molecule



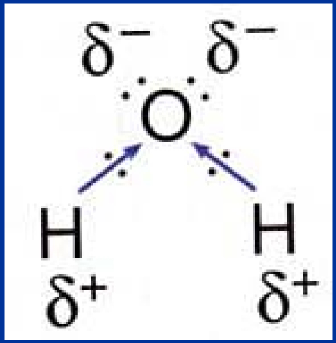
Lewis dot diagram

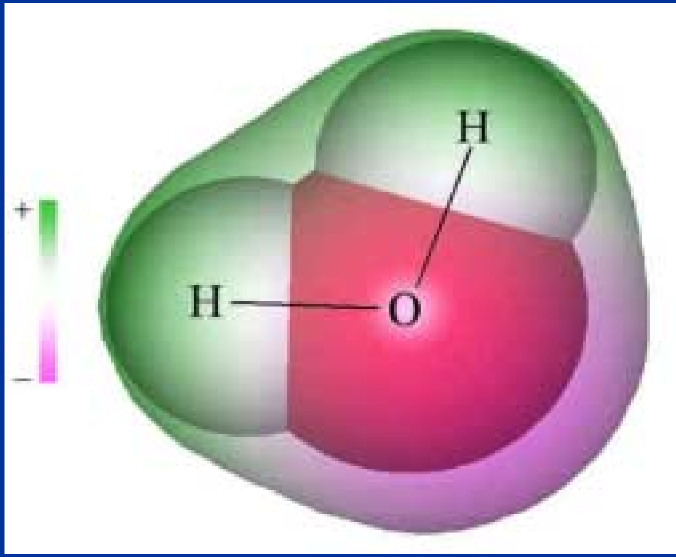


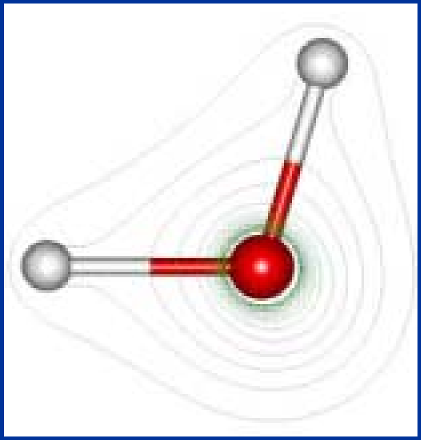


space filling model

O-H bonds are polarized because of the difference in electronegativity between the O and H atoms

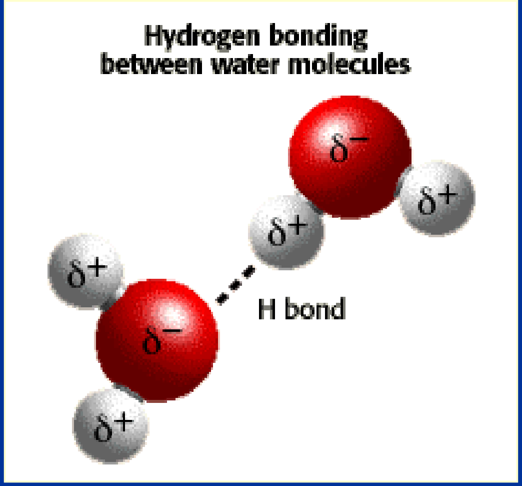


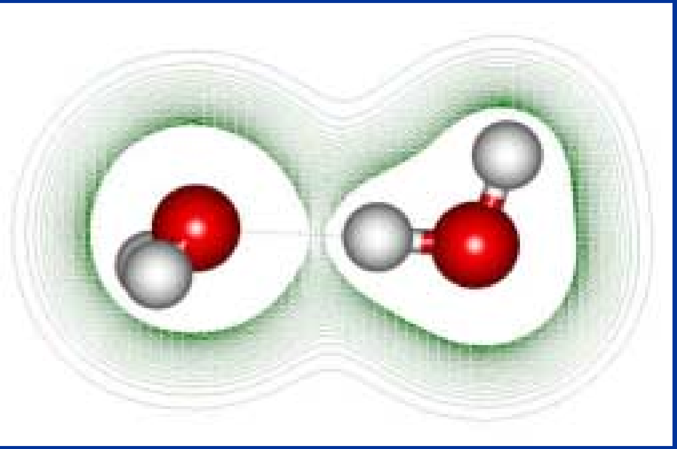


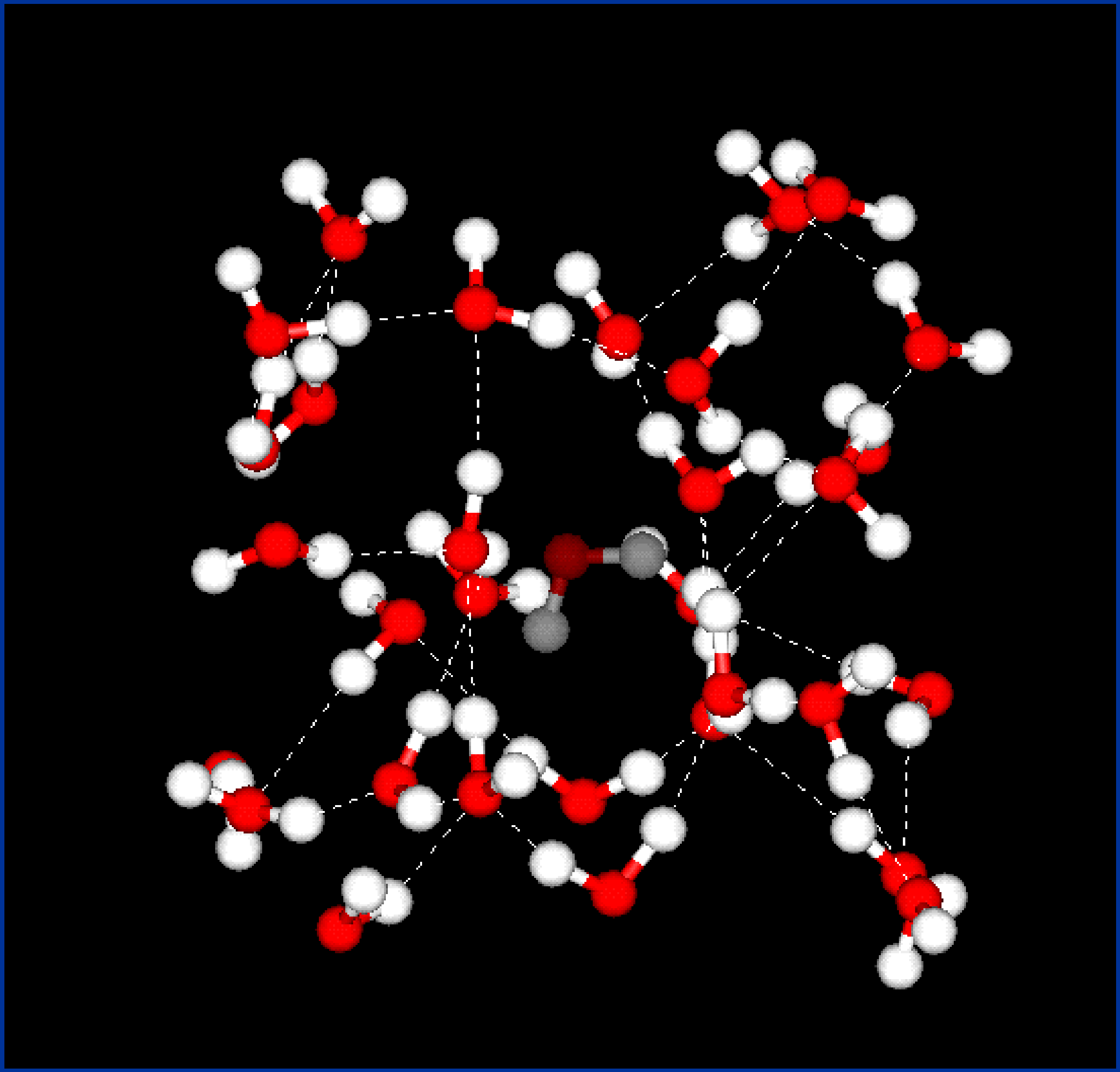


Hydrogen bonds

This unequal electron distribution results in strong non-bonding interactions between water molecules - hydrogen bonds



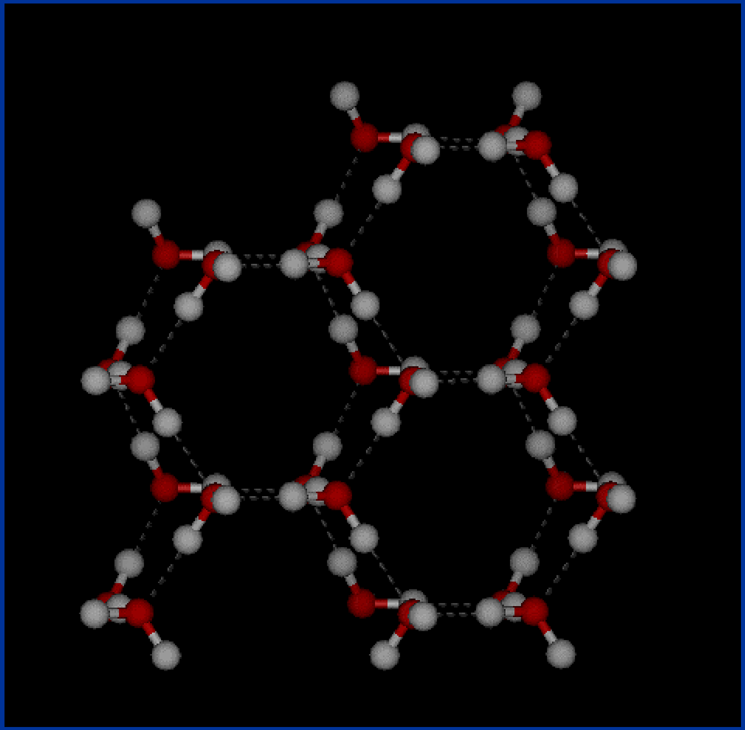




Hydrogen bonds in liquid water

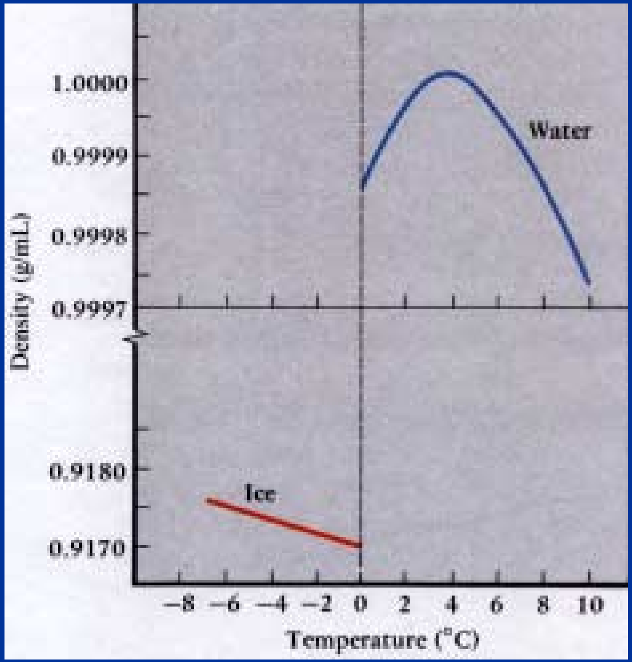
Consequences of hydrogen bonding in water

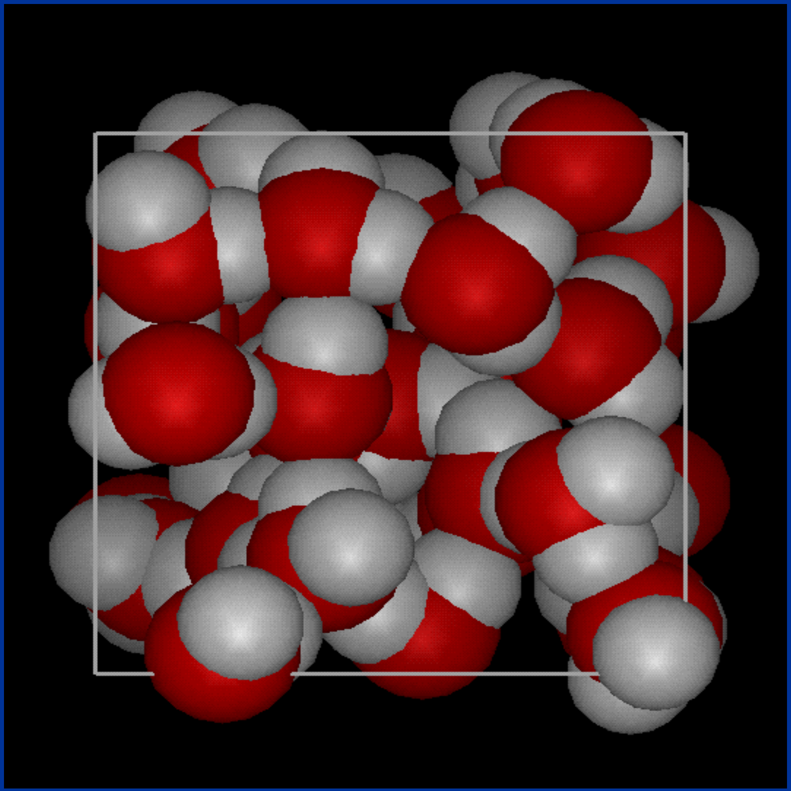
Ice floats because hydrogen bonds hold water molecules further apart in a solid than in a liquid - density of ice is less than density of water



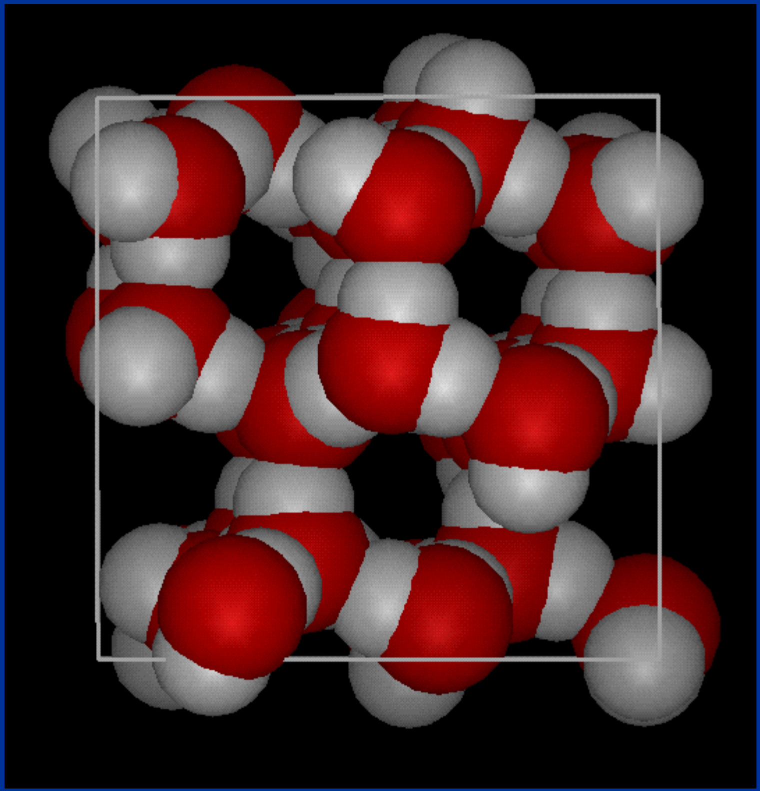
Density of ice at 0ºC - 0.9997 g/ml

Density of water at 0ºC - 0.9170 g/ml





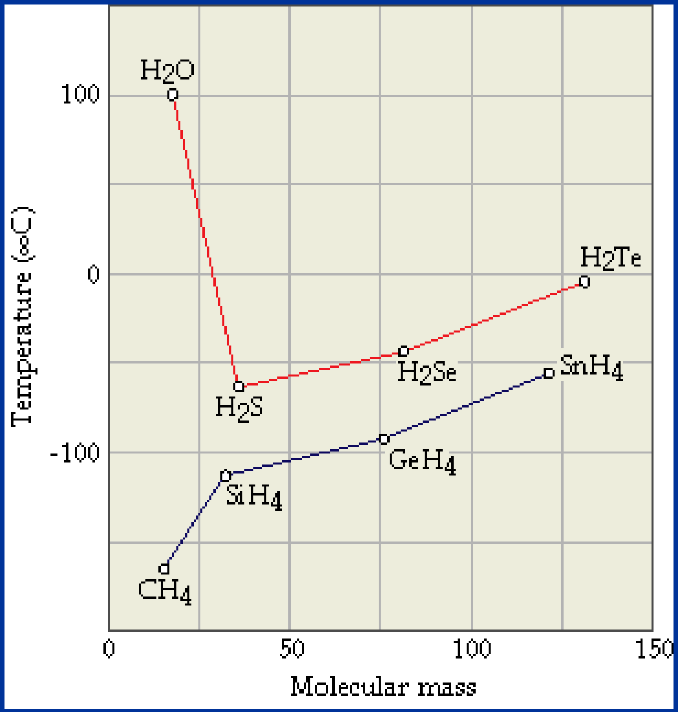
liquid water



solid water

http://www.nyu.edu/pages/mathmol/modules/water/info_water.html

Water has a high boiling point and high freezing point.



Boiling points vs molecular mass

If water were “normal” it would be a gas at room temperature.

CH_4, NH_3, freeze at lower temperatures than H_2O

Water has a high specific heat index.

It takes much more heat to raise the temperature of a volume of water than the same volume of air.

This is why water is used as a coolant.

Specific Heats of Some Common Substances

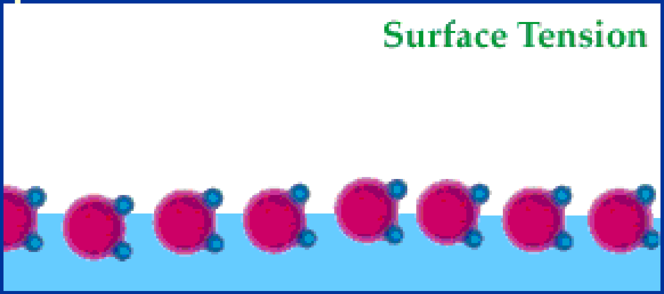
Substance	Specific Heat [cal/(g · °C)]
Water (liquid)	1.00
Water (solid)	0.50
Water (gas)	0.47
Ethyl alcohol	0.54
Wood	0.42
Aluminum	0.21
Glass	0.12
Iron	0.11
Copper	0.09
Silver	0.06
Gold	0.03

This property of water is a major determinant of global climates and rates of global climate change

- changes in temperatures are gradual
- “lake” effects

Water has a high surface tension

water molecules are cohesive - 'stick' to one another and to other polar molecules



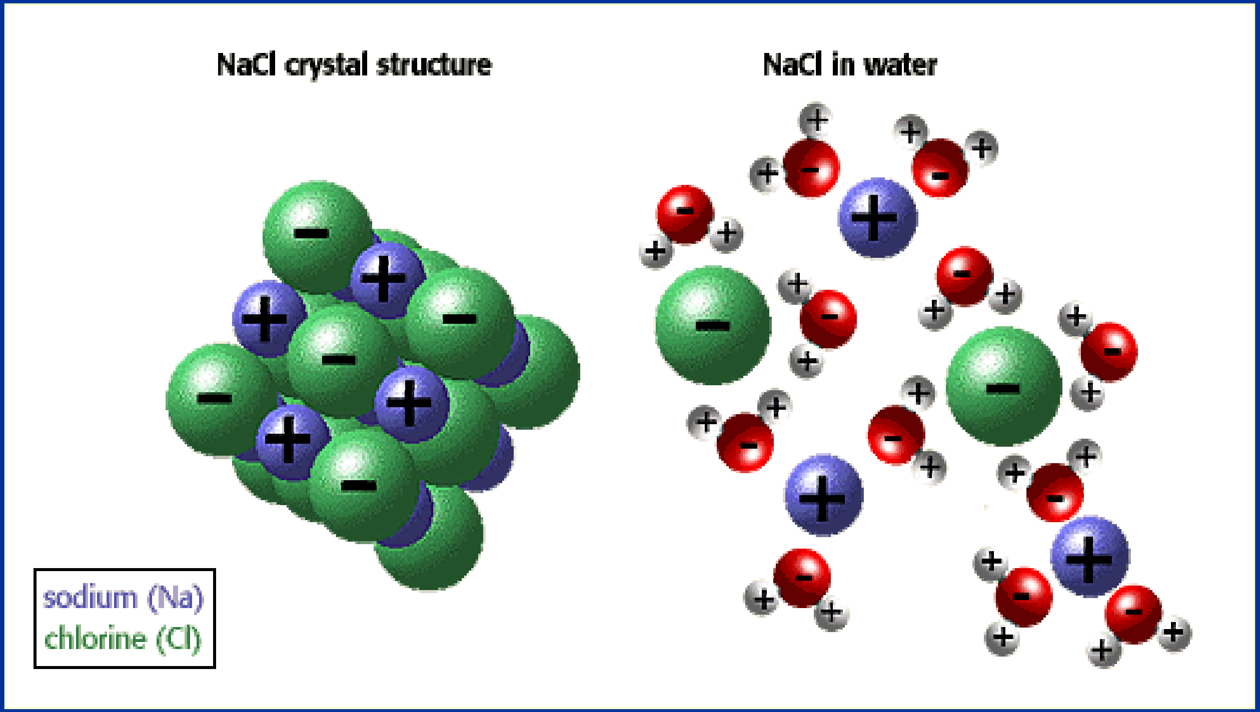
The surface tension makes air-water boundaries distinctive microhabitats.

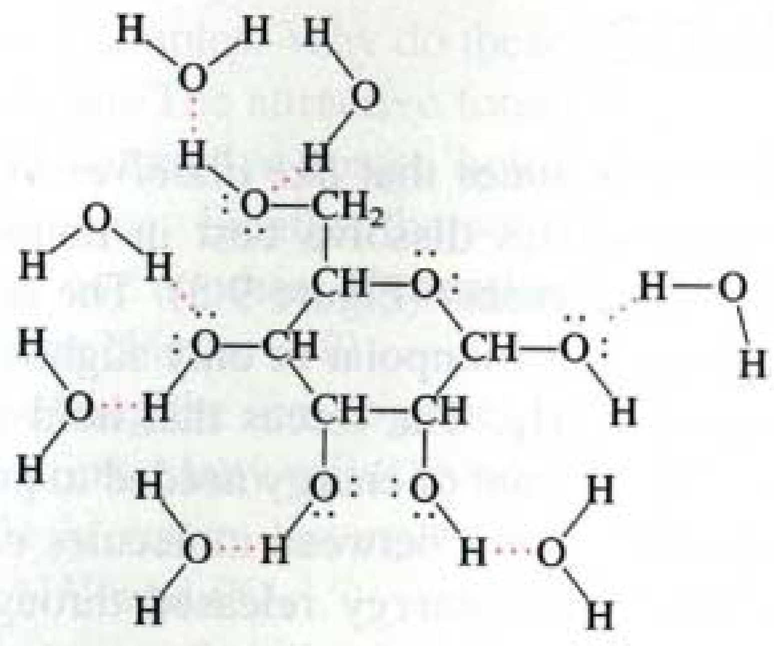
insect on water

Name	surface tension (dynes/cm at 20^{o}C)
Water	73
Methanol	22
Ethanol	22
Ether	17

“Universal” Solvent

Water being polar can dissolve ionic and polar compounds





Glucose
(soluble in water)

Polar compounds in water

Water is critical for the three-dimensional structure and activity of proteins, nucleic acids.

Since water is a “universal” solvent, water is easily polluted.

Water readily dissolves compounds (e.g. heavy metal ions, pesticides), and hard to purify.

“Hydrophobic effect”, or the exclusion of non-polar compounds is another unique property of water caused by the hydrogen bonds.

The hydrophobic effect is particularly important in the formation of cell membranes - water "squeezes" non-polar molecules together

Interesting Water websites

http://witcombe.sbc.edu/water/index.html

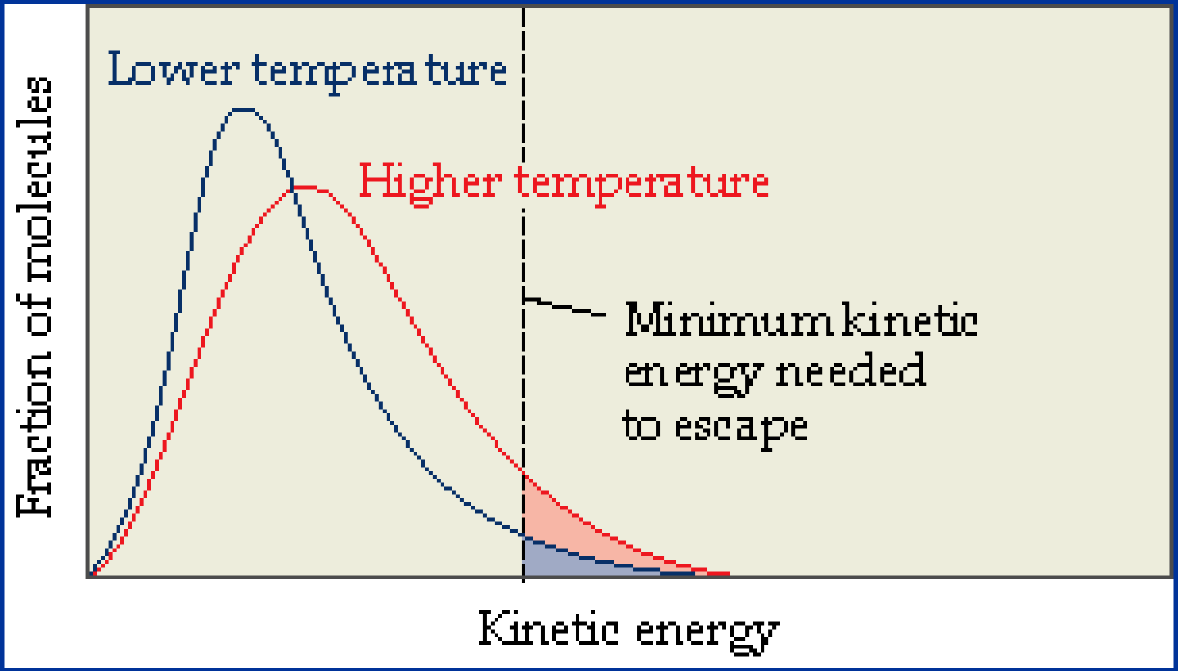
http://www.sbu.ac.uk/water/

http://www.nyu.edu/pages/mathmol/modules/water/info_water.html

Phase Changes

Molecules in a liquid are in constant motion; some moving faster, others slower.

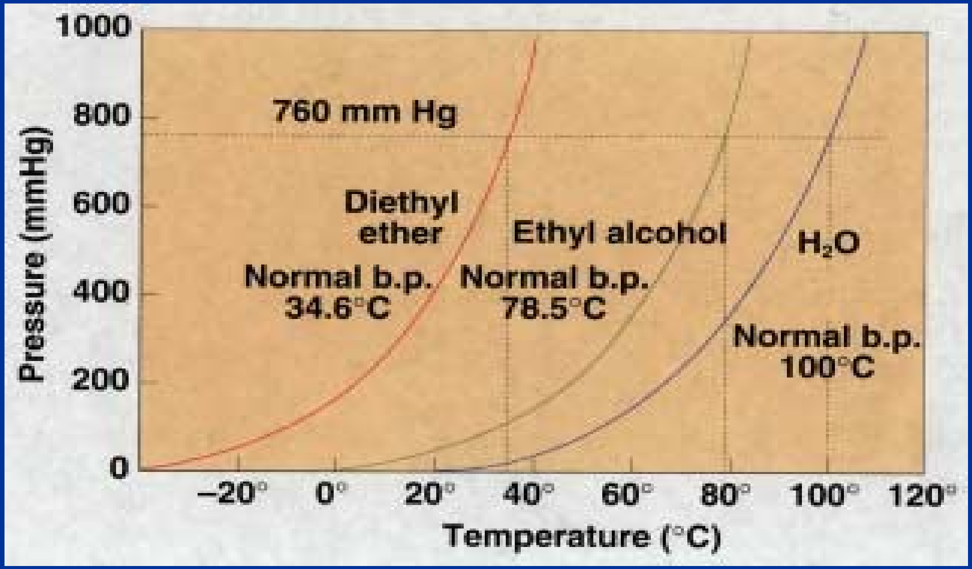
Those molecules with enough kinetic energy escape from the liquid surface, i.e. vaporize.



Condensation: When molecules in the gas phase collide with the liquid surface, they loose energy and return to the liquid.

At some point the rate of vaporization and the rate of condensation become equal and the system is at equilibrium.

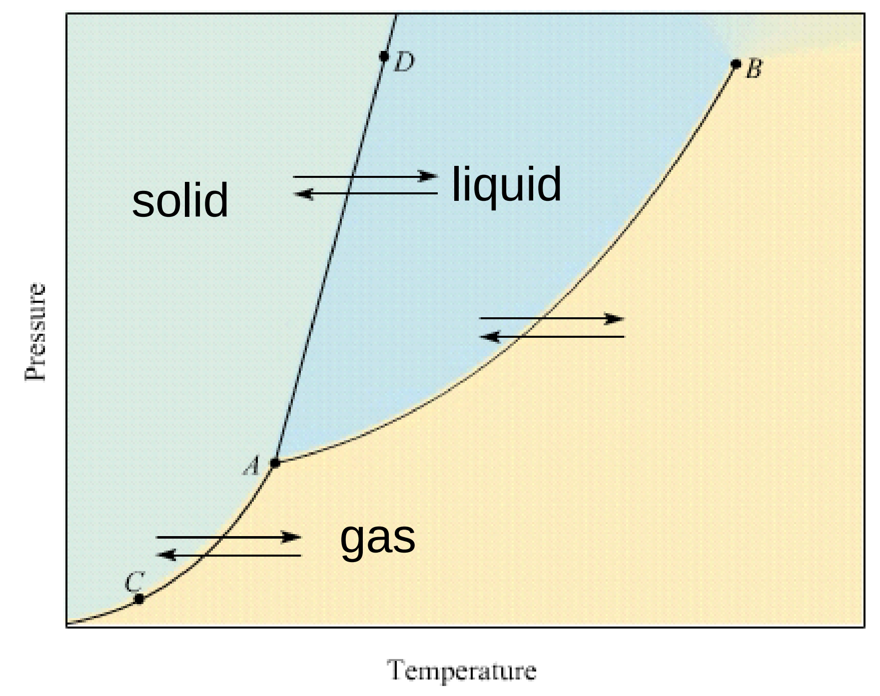
The partial pressure of the vapor above the liquid established at equilibrium is called the equilibrium vapor pressure or just vapor pressure.



Boiling Point - the temperature at which the vapor pressure of the liquid equals the atmospheric pressure.

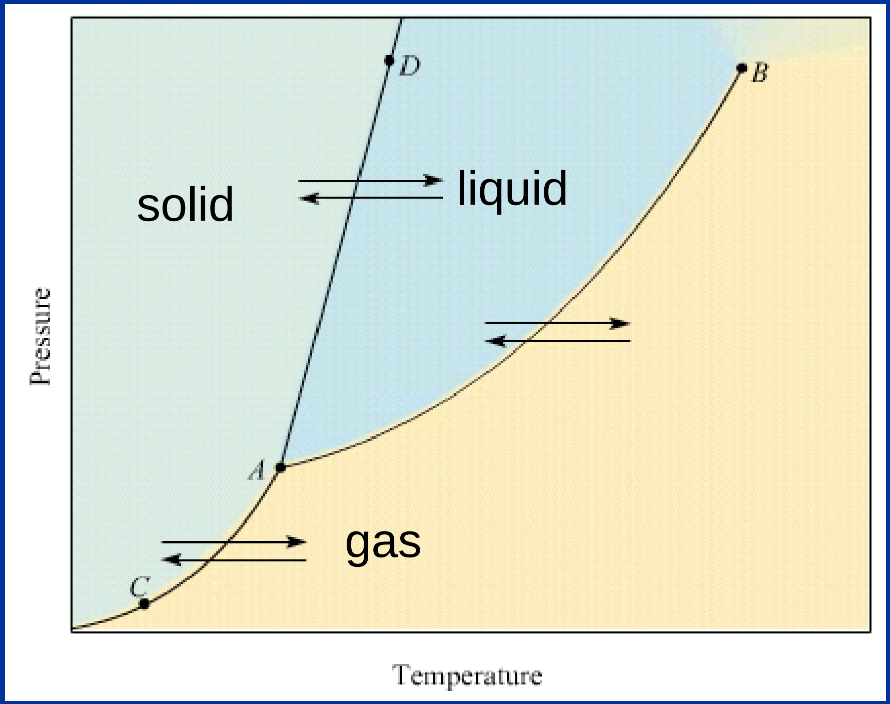
Normal boiling point - temperature at which the vapor pressure equals 1 atm.

Melting point - temperature at which a substance turns from solid to liquid.



The three phase changes can be brought about by changes in temperature or pressure:

Fusion or melting	solid --> liquid
Vaporization	liquid --> gas
Sublimation	solid --> gas



Solutions

Solutions - homogenous mixture of two or more components

Liquid solutions

Solute (gas, liquid or solid) dissolved in a liquid **Solvent**

If solute and solvent are liquids, and the resulting solution is homogenous, the two are said to be **miscible**.

Concentrations of Solutions

$$\text{Mass percentage} = \frac{\text{mass of component}}{\text{total mass of mixture}} \times 100\%$$

$$\text{molality (m)} = \frac{\text{moles of solute}}{\text{kilograms of solvent}} \quad \text{(units mol/kg)}$$

$$\text{molarity (M)} = \frac{\text{moles of solute}}{\text{liter of solution}} \quad \text{(units mol/l)}$$

$$\text{Mole fraction} = \frac{\text{moles of component}}{\text{total number of moles in mixture}}$$

For a solution of two components A & B

$$X_A = \frac{n_A}{n_A + n_B}$$

$$X_B = 1 - X_A$$

Effect of Temperature and Pressure on Solubility

$$NH_4NO_3(s) \rightleftharpoons NH_4NO_3(aq)$$

Dissolution is often accompanied by a change in temperature.

For solid and liquid solutes, temperature can effect solubility; pressure has little or no effect.

For gas solutes - temperature and pressure can effect solubility

$$O_2(g) \rightleftharpoons O_2(aq)$$

$$p_{O_2} = K_H \ X_{O_2}$$ Henry's Law

where p_{O_2} is the partial pressure of the O_2 above the solution

X_{O_2} is the mole fraction of the gas solute in solution

K_H - Henry's constant (units of pressure, as expressed above)

$$p_{O_2} = K_H \ [O_2]$$

units of K_H: L-atm/mol

Henry’s law determines the amount of dissolved oxygen in water at a given temperature.

At 25^{o}C, the solubility of O_2 is 8.7milligram/liter of water

Verify this if at 25^{o}C K_H is 7.7x10^{2} L-atm/mol, and p_{O_2} is 0.21 atm

Thermal pollution effects the mole fraction of O_2 in water.