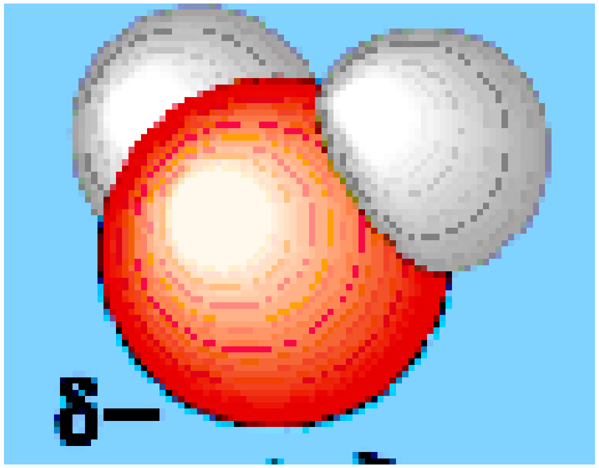
Properties of Water

- Polar molecule
- Cohesion and adhesion
- High specific heat
- Density – greatest at 4^oC
- Universal solvent of life

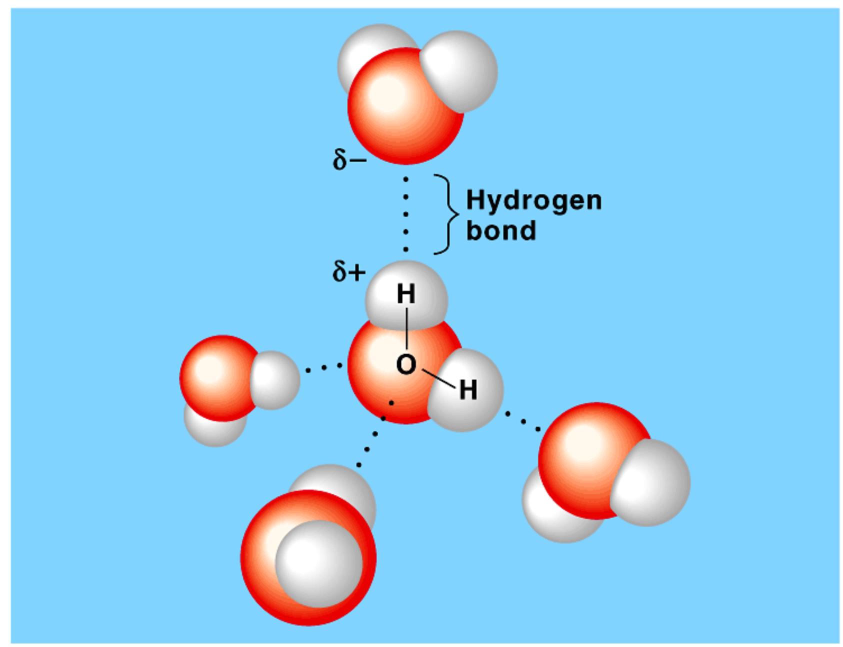
Polarity of Water

- In a water molecule two hydrogen atoms form single polar covalent bonds with an oxygen atom. Gives water more structure than other liquids
  - Because oxygen is more electronegative, the region around oxygen has a partial negative charge.
  - The region near the two hydrogen atoms has a partial positive charge.
- A water molecule is a polar molecule with opposite ends of the molecule with opposite charges.

E.N. of O = 3.5
and H = 2.1



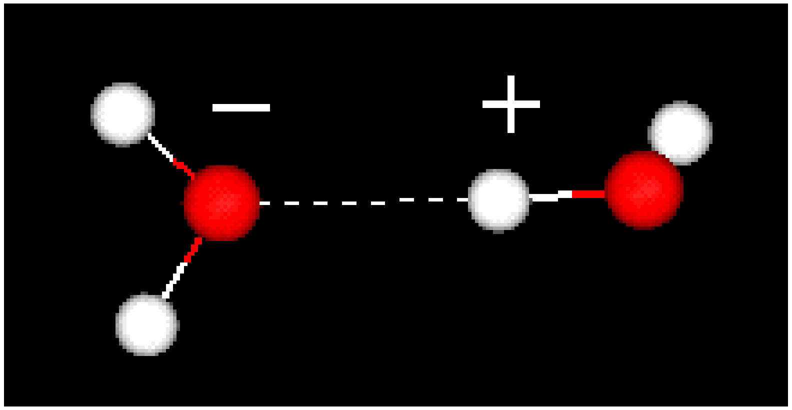
- Water has a variety of unusual properties because of attractions between these polar molecules.
  - The slightly negative regions of one molecule are attracted to the slightly positive regions of nearby molecules, forming a hydrogen bond.
  - Each water molecule can form hydrogen bonds with up to four neighbors.



HYDROGEN BONDS

- Hold water molecules together
- Each water molecule can form a maximum of 4 hydrogen bonds
- The hydrogen bonds joining water molecules are weak (~ 5-10 kcal/mol) about 1/20th as strong as covalent bonds.
- They form, break, and reform with great frequency

- Extraordinary Properties that are a result of hydrogen bonds.
  - Cohesive behavior
  - Resists changes in temperature
  - High heat of vaporization
  - Expands when it freezes
  - Versatile solvent



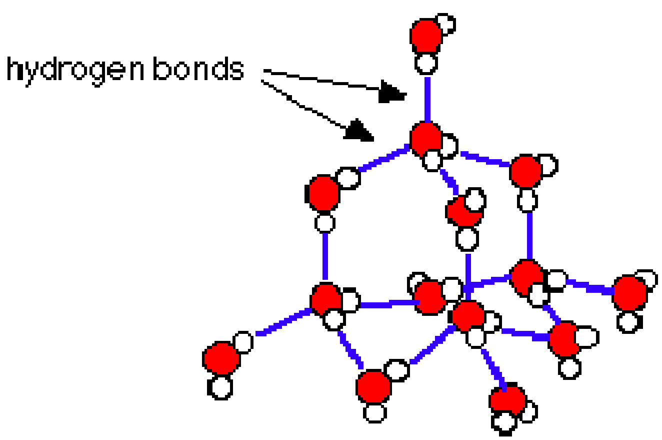
Density of Water

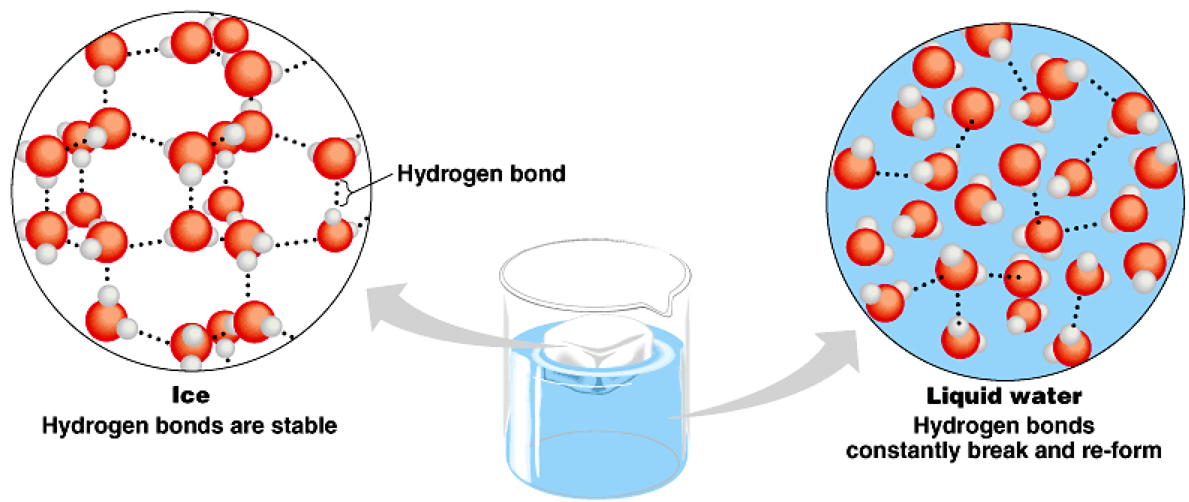
- Most dense at 4^oC
- Contracts until 4^oC
- Expands from 4^oC to 0^oC

The density of water:

1. Prevents water from freezing from the bottom up.
2. Ice forms on the surface first—the freezing of the water releases heat to the water below creating insulation.
3. Makes transition between season less abrupt.

- When water reaches 0^{o}C, water becomes locked into a crystalline lattice with each molecule bonded to the maximum of four partners.
- As ice starts to melt, some of the hydrogen bonds break and some water molecules can slip closer together than they can while in the ice state.
- Ice is about 10% less dense than water at 4^{o}C.

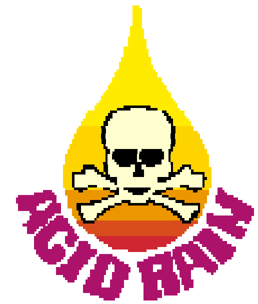


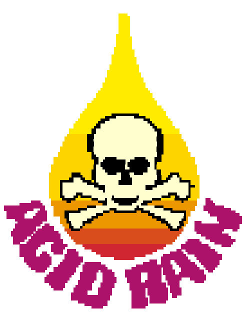


- **A simpler way to view this process is that a water molecule dissociates into a hydrogen ion and a hydroxide ion:**
  - **$H_2O \Leftrightarrow H^+ + OH^-$**
- **This reaction is reversible.**
- **At equilibrium the concentration of water molecules greatly exceeds that of H^+ and OH^-.**
- **In pure water only one water molecule in every 554 million is dissociated.**
  - **At equilibrium, the concentration of H^+ or OH^- is 10^{-7}M (25°C) .**

Acid Precipitation

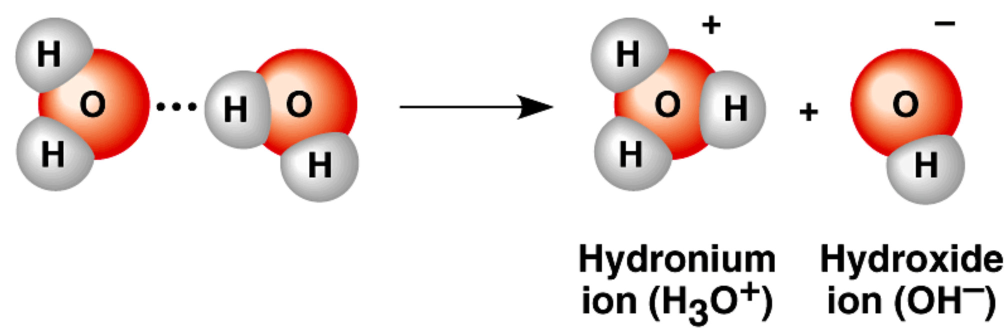
- Rain, snow or fog with more strongly acidic than pH of 5.6
- West Virginia has recorded 1.5
- East Tennessee reported 4.2 in 2000
- Occurs when sulfur oxides and nitrogen oxides react with water in the atmosphere
  - **Lowers pH of soil which affects mineral solubility – decline of forests**
  - **Lower pH of lakes and ponds – In the Western Adirondack Mountains, there are lakes with a pH <5 that have no fish.**





Dissociation of Water Molecules

- Occasionally, a hydrogen atom shared by two water molecules shifts from one molecule to the other.
  - The hydrogen atom leaves its electron behind and is transferred as a single proton - a **hydrogen ion** (H^+).
  - The water molecule that lost a proton is now a **hydroxide ion** (OH^-).
  - The water molecule with the extra proton is a hydronium ion (H_3O^+).



Unnumbered Fig. 3.47

Ionization of Water

Occasionally, in water, a H^+ is transferred between H_2O molecules

```
  ..         ..                  ..               ..
H:O:  +    :O:H               H:O:H +      +   :O:H-
  ..         ..     ⇌           ..               ..
  H          H                  H
```

water molecules **hydronium ion (+)** **hydroxide ion (-)**

Pure Water is Neutral

Pure water contains small, but equal amounts of ions: H_3O^+ and OH^-

$$H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$$

hydronium ion **hydroxide ion**

1×10^{-7} M **1×10^{-7} M**

Ion Product of Water K_w

[ ] = Molar concentration

$$K_w = [H_3O^+][OH^-]$$

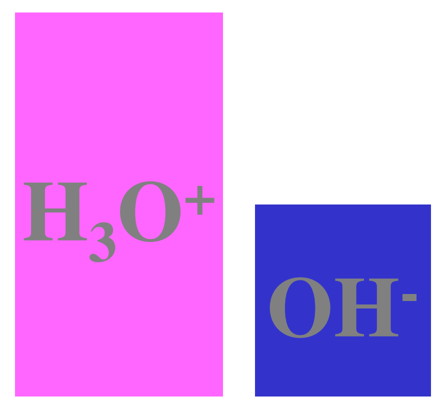
$$= [1 \times 10^{-7}][1 \times 10^{-7}]$$

$$= 1 \times 10^{-14}$$

Acids

- Increase H^+
- HCl (g) + H_2O (l) $\longrightarrow$ H_3O^+ (aq) + Cl^- (aq)
- More $[H_3O^+]$ than water $> 1 \times 10^{-7}M$
- As H_3O^+ increases, OH^- decreases

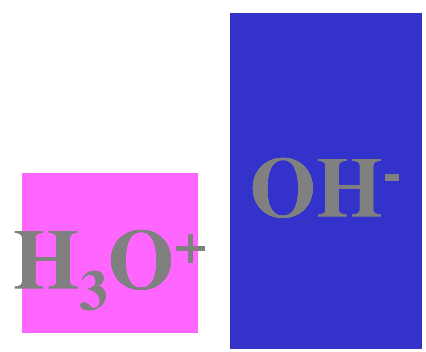
$[H_3O^+] > [OH^-]$



Bases

- Increase the hydroxide ions (OH^-)
- $NaOH\ (s) \xrightarrow{H_2O} Na^+(aq) \quad + \quad OH^-\ (aq)$
- More $[OH^-]$ than water, $[OH^-] > 1 \times 10^{-7}M$
- When OH^- increases, H_3O^+ decreases

$$[OH^-] > [H_3O^+]$$



Using K_w

The $[OH^-]$ of a solution is 1.0×10^{-3} M. What is the $[H_3O^+]$?

$$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$$

$$[H_3O^+] = \frac{1.0 \times 10^{-14}}{[OH^-]}$$

$$[H_3O^+] = \frac{1.0 \times 10^{-14}}{1.0 \times 10^{-3}} = 1.0 \times 10^{-11}\ \text{M}$$

Acid Rain

- **Unpolluted rain has a pH of 5.6**
- **Rain with a pH below 5.6 is “acid rain“**
- **CO_2 in the air forms carbonic acid**

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

- **Adds to H^+ of rain**

$$H_2CO_3 \longrightarrow H^+ (aq) + HCO_3\text{-}(aq)$$

Formation of acid rain:

1. **Emission of sulfur and nitrogen oxides from the burning of fuels especially coal with high S content, power stations, oil refineries, vehicles as well as bacterial decomposition, and lighting hitting N_2**

SO_2 26 million tons in 1980

NO and NO_2 22 million tons in 1980

Mt. St Helens (1980) 400,000 tons SO_2

2. **Reactions in the atmosphere form SO_3**

$$2SO_2 + O_2 \longrightarrow 2\ SO_3$$

3. **Reactions with atmosphere water form acids**

$$SO_3 + H_2O \longrightarrow H_2SO_4 \text{ sulfuric acid}$$

$$NO + H_2O \longrightarrow HNO_2 \text{ nitrous acid}$$

$$HNO_2 + H_2O \longrightarrow HNO_3 \text{ nitric acid}$$

4. Effects of Acid Rain

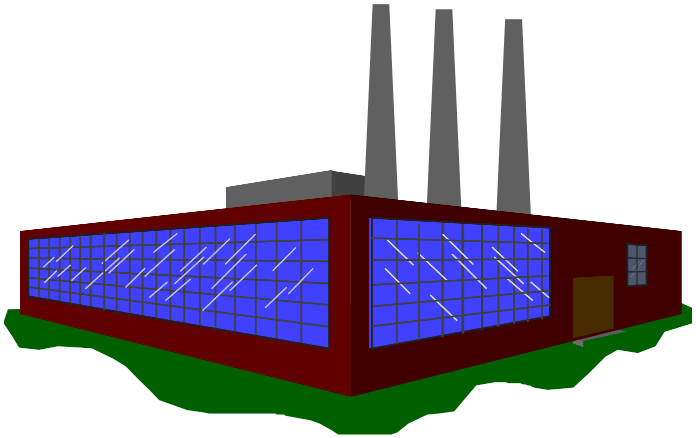
- Decline in fish populations in rivers and lasts due to toxic effect of Al leached from soil by acid rain

- Extensive fish kills in spring from runoff due to accumulation of large amounts of acid on the snow

- Dissolves minerals Mg, Ca, and K from the soil and waxy coatings that protect leaves from bacteria

- Corrodes metals, textiles, paper and leather

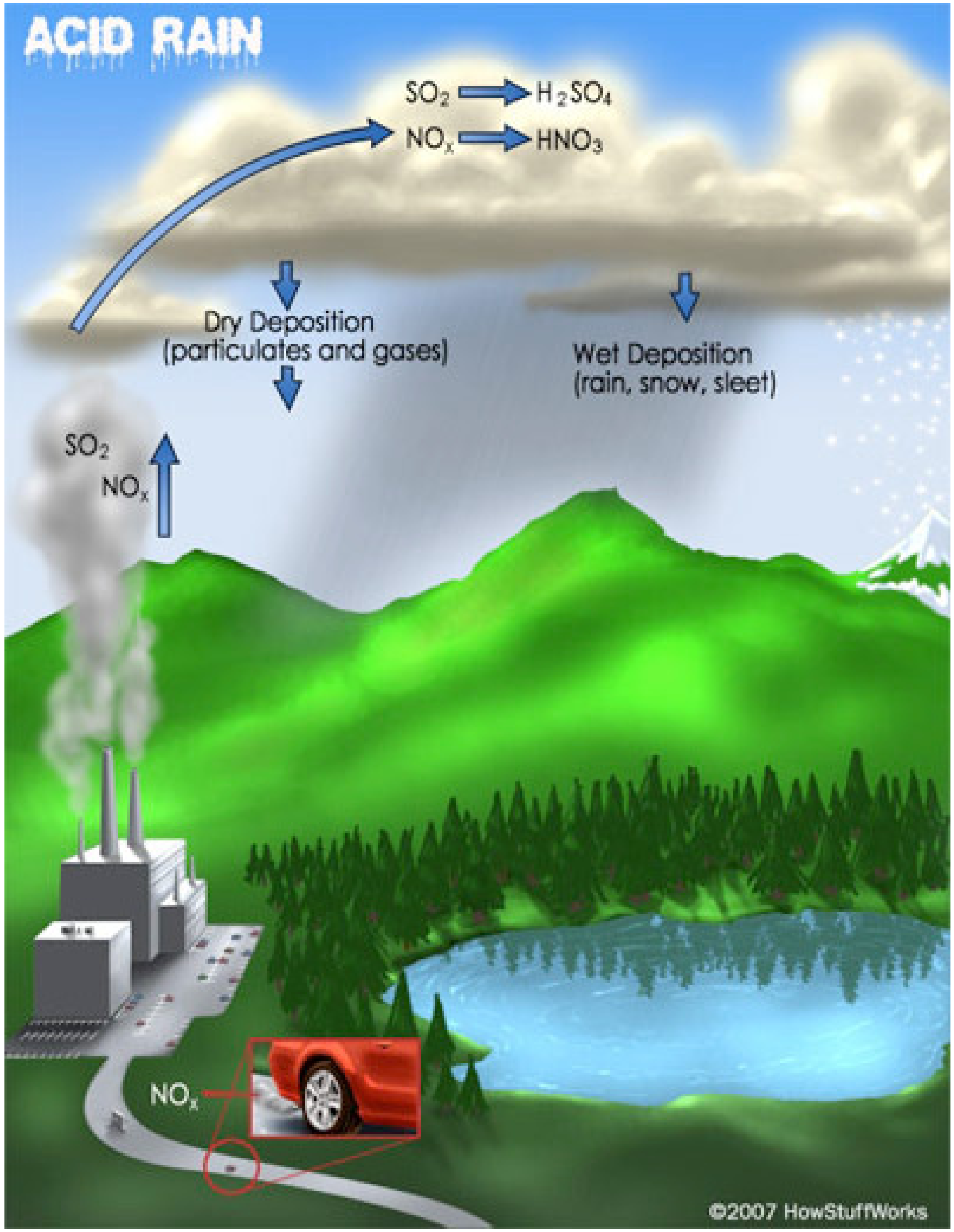
Sources of Acid Rain



- Power stations
- Oil refineries
- Coal with high S content
- Car and truck emissions
- Bacterial decomposition, and lighting hitting N_2

Acid Deposition

- **Acid Rain refers to the deposition of acidic components in either wet or dry forms**
- **Defined by the pH of the liquid. Less than 7 pH is acidic, more than 7 is basic**
- **Natural acid rain can be caused by volcanic emissions and biological processes**
- **“Clean” rain has a natural acidity of about 5.2 on the pH scale due to water reacting with carbon dioxide in the air to form carbonic acid**
- $H_2O\ (l) + CO_2\ (g) \rightarrow H_2CO_3\ (aq)$
- $2\ H_2O\ (l) + H_2CO_3\ (aq) \leftrightarrow CO_3^{2-}\ (aq) + 2\ H_3O^+\ (aq)$


ACID RAIN
SO_2 → H_2SO_4
NO_x → HNO_3
Dry Deposition
(particulates and gases)
Wet Deposition
(rain, snow, sleet)
SO_2
NO_x
NO_x
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Causes for Acid Rain

- Human emissions of sulfur dioxide and nitrogen oxides contribute to the acidification of rain
- Emissions began during the industrial revolution, remaining unchecked until the 1970s
- Biggest contributor is the burning of coal
- Annually 70Tg (10^{12} g) of Sulfur emissions comes from fossil fuel burning, compared to 8Tg from volcanoes and 2.8Tg from wildfires

The Coal Power Plant Problem

- Burning coal is extremely cheap and efficient but dirty, releasing sulfur dioxide which becomes sulfuric acid in the atmosphere
- Areas downwind of power plants receive heavy acid rain
- Smoke stacks built to counteract direct deposition of sulfuric acid only spread the problem

Effects of Acid Rain

- Not many things can grow in acidic conditions
- Low pH and high aluminum concentrations can damage or kill fish and aquatic populations
- Soils can be damaged by the hydronium ion, which mobilizes aluminum and encourages leaching of minerals such as magnesium essential for plant life
- Forests suffer from soil damage, however most food crops are unharmed because the nutrients lost are replaced in fertilizer

Other Effects

- Monuments made of Calcium Carbonate (limestone and marble) will react with acid rain to form Gypsum
- Increases the oxidation rate of metals such as copper and bronze

Areas of Highest Concern

- Current problem areas are:
- Eastern United States
- South Western Canada
- Eastern Europe
- East Coast of China

- Potential future problem areas:
- Southern India
- West Africa
- Indonesia
- Thailand

Prevention

- Coal burning power plants use Flue gas desulfurization requiring a reaction tower that extracts the sulfuric acid by reacting it with lime or limestone slurry and removing the product with scrubbers
- Reduction in automotive emissions cuts down on nitrogen oxides
- Emissions trading put into practice to put economic incentive into cleaning industrial activities

Flue-gas desulfurization

$CaCO_3$ (solid) + SO_2 (gas) $\rightarrow$ $CaSO_3$ (solid) + CO_2 (gas)

$Ca(OH)_2$ (solid) + SO_2 (gas) $\rightarrow$ $CaSO_3$ (solid) + H_2O (liquid)

$Mg(OH)_2$ (solid) + SO_2 (gas) $\rightarrow$ $MgSO_3$ (solid) + H_2O (liquid)

$CaSO_3$ (solid) + H_2O (liquid) + ½O_2 (gas) $\rightarrow$ $CaSO_4$ (solid) + H_2O

SO_2 (gas) + H_2O (liquid) + ½O_2 (gas)$\rightarrow$ SO_4^{2-} (solid) + $2H^+$

HCO_3^- + H^+ $\rightarrow$ H_2O (liquid) + CO_2 (gas)

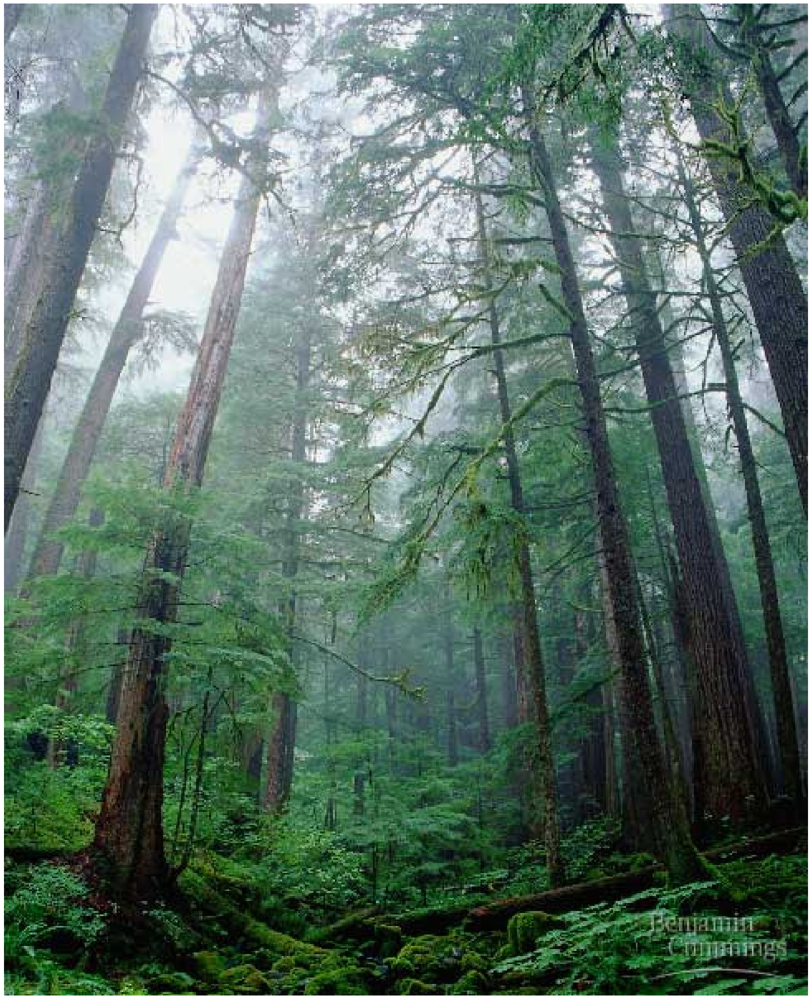
$2NaOH$ (aq) + SO_2 (gas) $\rightarrow$ Na_2SO_3 (aq) + H_2O (liquid)

Organisms Depend on Cohesion

Hydrogen bonds hold the substance together, a phenomenon called cohesion

- **Cohesion is responsible for the transport of the water column in plants**
- **Cohesion among water molecules plays a key role in the transport of water against gravity in plants**

- **Adhesion, clinging of one substance to another, contributes too, as water adheres to the wall of the vessels.**



- **Surface tension,** a measure of the force necessary to stretch or break the surface of a liquid, is related to cohesion.
  - Water has a greater surface tension than most other liquids because hydrogen bonds among surface water molecules resist stretching or breaking the surface.
  - Water behaves as if covered by an invisible film.
  - Some animals can stand, walk, or run on water without breaking the surface.

Fig. 3.3

Moderates Temperatures on Earth

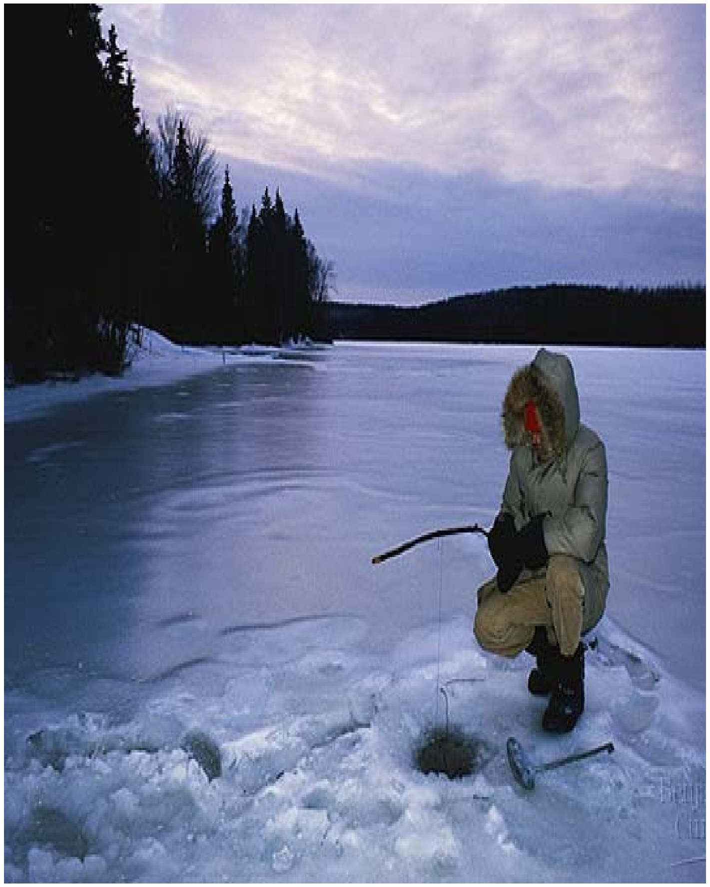
Water stabilizes air temperatures by absorbing heat from warmer air and releasing heat to cooler air.
Water can absorb or release relatively large amounts of heat with only a slight change in its own temperature.

Celsius Scale at Sea Level	
$100^{o}C$	Water boils
$37^{o}C$	Human body temperature
$23^{o}C$	Room temperature
$0^{o}C$	Water freezes

Specific Heat is the amount of heat that must be absorbed or lost for one gram of a substance to change its temperature by $1^{o}C$.

Three-fourths of the earth is covered by water. The water serves as a large heat sink responsible for:

1. Prevention of temperature fluctuations that are outside the range suitable for life.
2. Coastal areas having a mild climate
3. A stable marine environment



Evaporative Cooling

- The cooling of a surface occurs when the liquid evaporates
- This is responsible for:
  - **Moderating earth's climate**
  - **Stabilizes temperature in aquatic ecosystems**
  - **Preventing organisms from overheating**

Solvent for Life

- Solution
  - Solute
  - solvent
- Aqueous solution
- Hydrophilic
  - Ionic compounds dissolve in water
  - Polar molecules (generally) are water soluble
- Hydrophobic
  - Nonpolar compounds