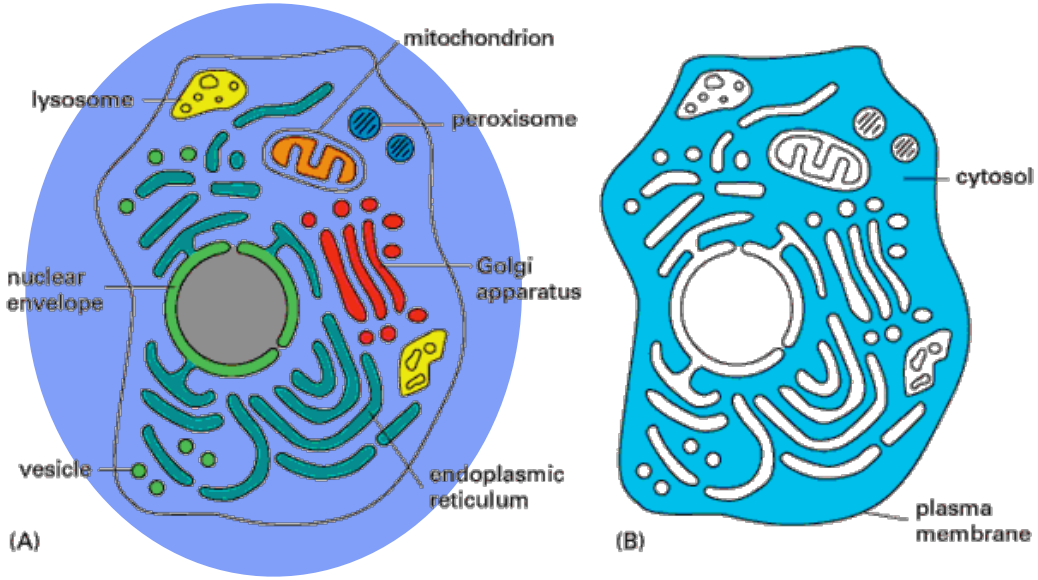
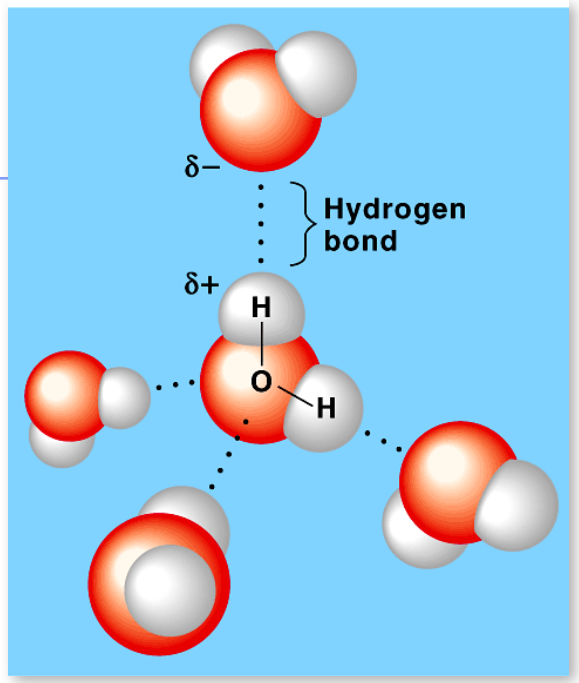
Properties of Water

Why study water?

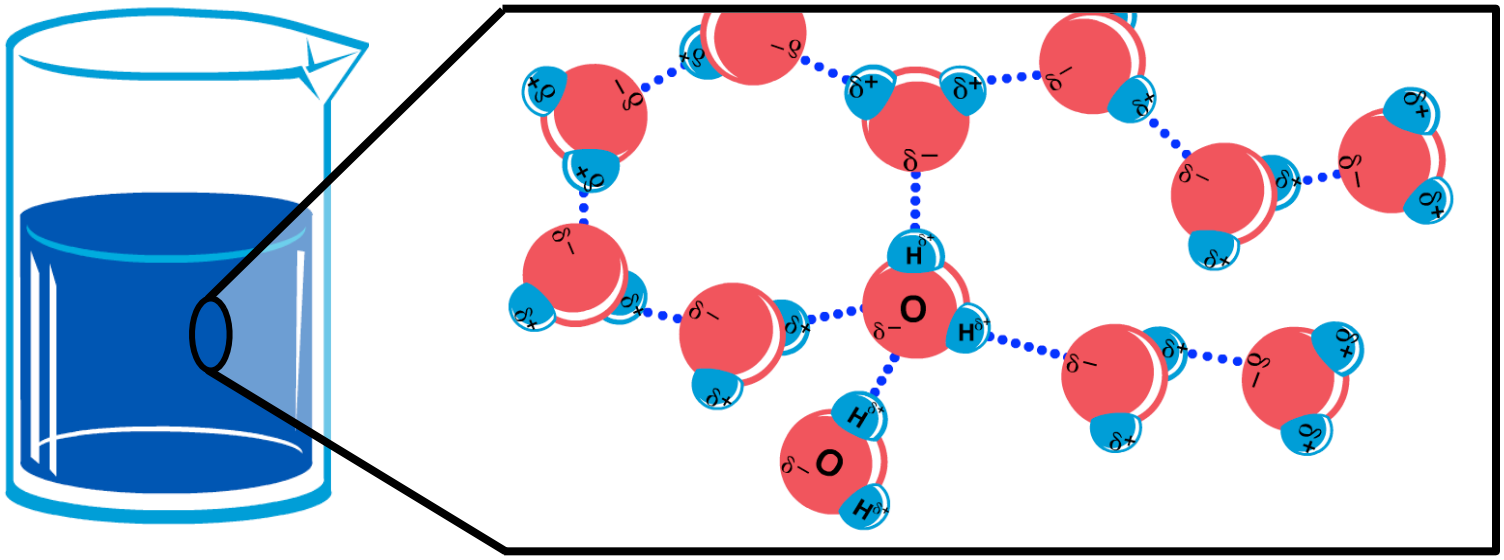
- Life began and evolved in water for 3 billion years before spreading to land.
- Today all life remains tied to water.
  - Cells are surrounded by a watery matrix referred to as interstitial fluid.
  - On the inside, cell are made up of 70-95% water, including the inner fluid called the cytosol.



Water is a Polar Molecule



- H_2O molecules Hydrogen bond with each other
  - δ^+ H attracted to δ^- O
  - H-bonds are 1/20 the strength of covalent bonds
  - This creates a sticky molecule



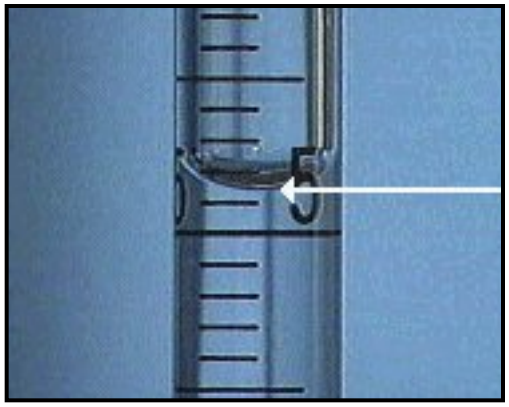
Emergent Properties of Water facilitate having an environment for life

- **Special properties of water**
  1. **Cohesive & Adhesive Behavior**
     - surface tension, capillary action
  2. **Able to moderate temperatures**
     - high specific heat
       - water stores heat
     - high heat of vaporization
       - heats & cools slowly
  3. **Lower density as a solid**
     - ice floats
  4. **Versatile solvent**
     - many molecules dissolve in H_2O
     - results in hydrophilic interactions
     - also causes hydrophobic exclusion

1. Cohesion & Adhesion

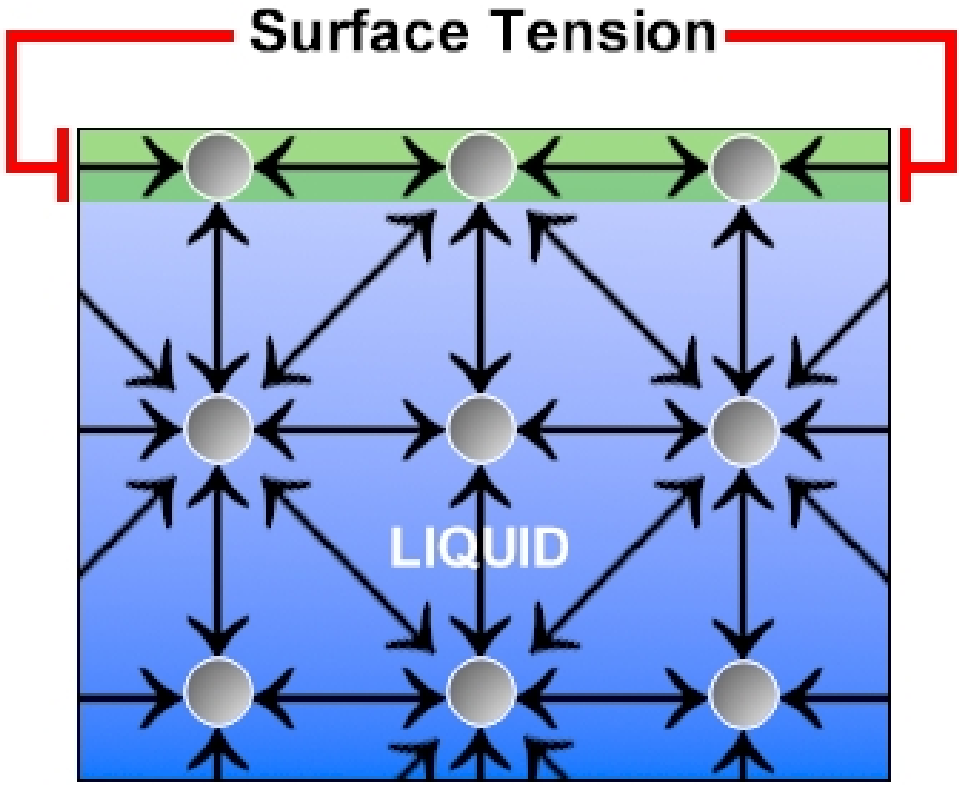
- **Cohesion:**
  - H-bonding between H_2O molecules
  - Water is "sticky"
    - Leads to surface tension
    - Allows you to drink from a straw. Higher water molecules pull the ones below up with them.

- **Adhesion:**
  - H-bonding or intermolecular forces between H_2O & other substances
    - With Cohesion allows for capillary action
    - Causes the sides of water's meniscus to climb up walls a graduated cylinder
    - Causes water to climb up paper towel



Surface Tension

- A measure of how difficult it is to stretch or break the surface of a liquid.
- The interface between water and air has an ordered arrangement of water molecules, hydrogen bonded to one another and the water below.
- Creates a film-like appearance at the surface of water

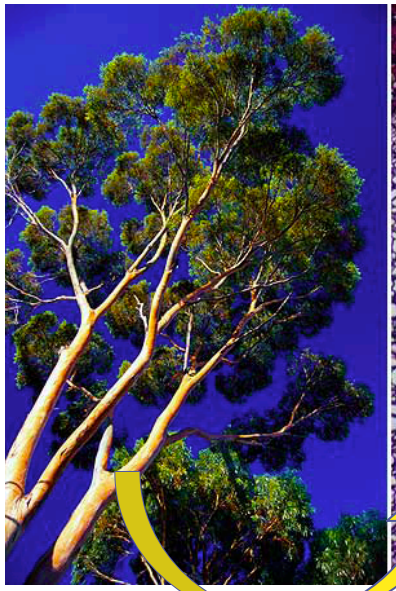


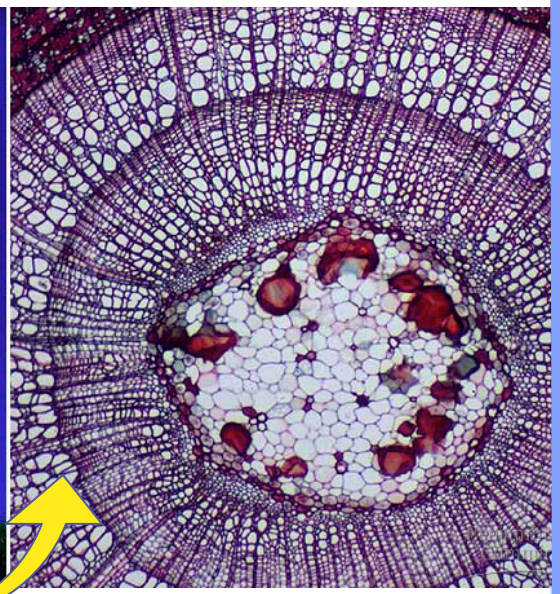
How does H_2O get to top of trees?

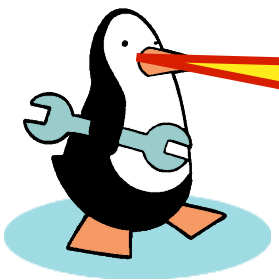
Capillary Action

(the movement of water up small tubes)

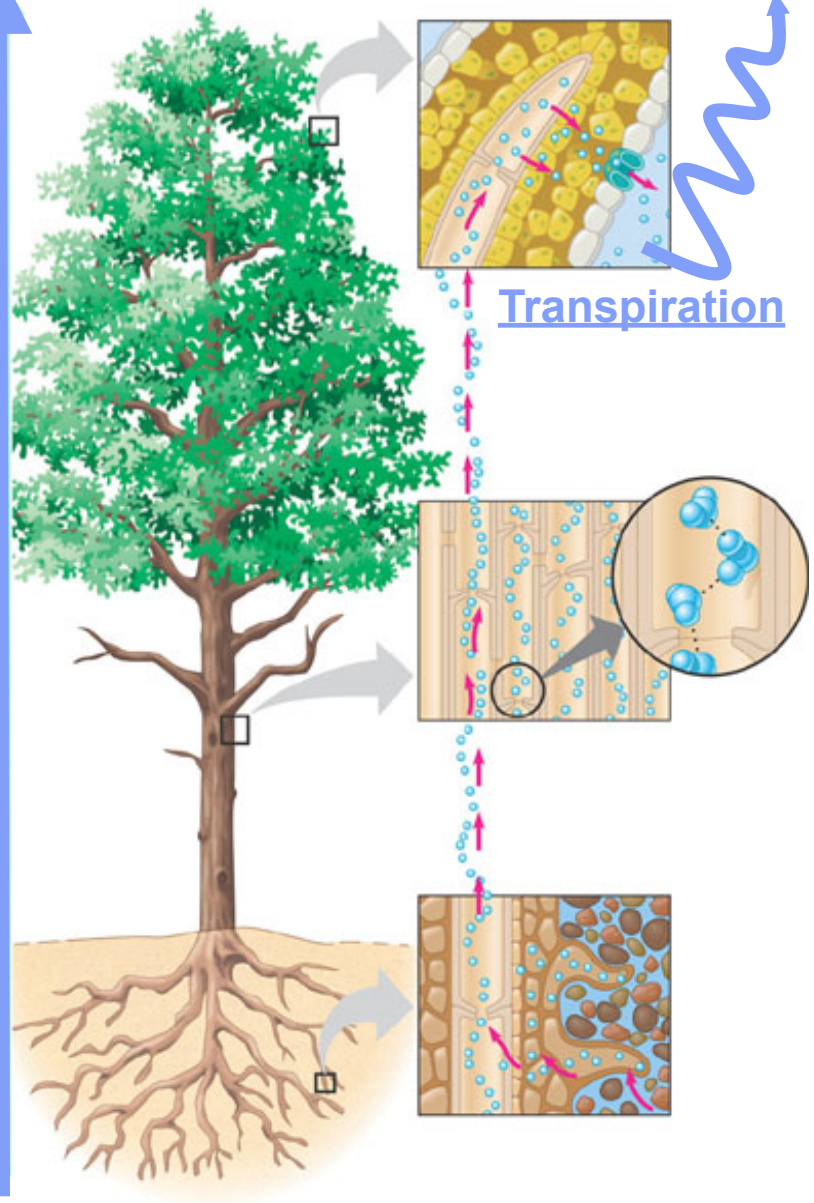
is built on cohesion & adhesion



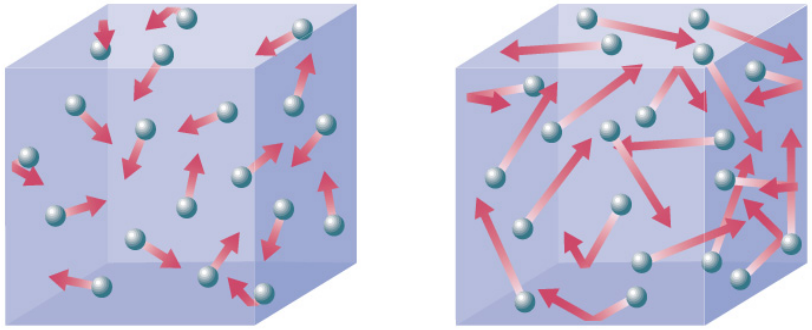




Water transport with ZERO energy expenditure!



Some terminology



Longer arrows mean higher average speed.

- **Thermal Energy**: kinetic energy due to disordered motions and vibrations of microscopic particles such as molecules and atoms.

  More motion = More Thermal Energy

- **Temperature:** a measurement of the average kinetic energy of the molecules in an object or system

  Measured with a thermometer or a calorimeter

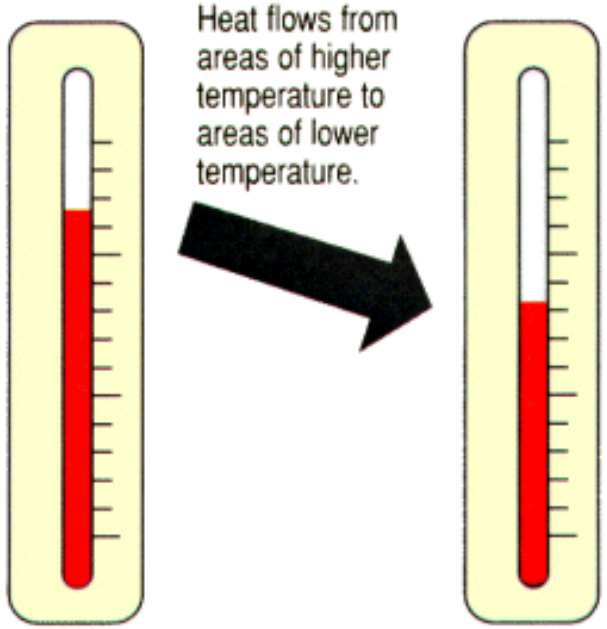
  It is a means of determining the internal energy contained within the system.

Some terminology

- **Temperature:** a measurement of the average kinetic energy of the molecules in an object or system

- **Heat:** the transfers of thermal energy by means of kinetic energy of the particles in a system.
  - Heat is transferred by particles bouncing into each other.

- Heat always refers to the transfer of energy between systems (or bodies), not to energy contained within the systems (or bodies).

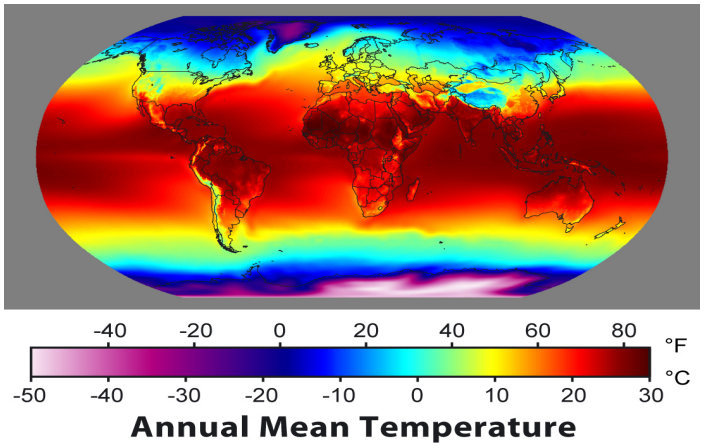


2. Specific heat

- **Specific Heat:** The amount of heat a substance must absorb or lose for 1 g of that substance to change its temperatures by 1°C

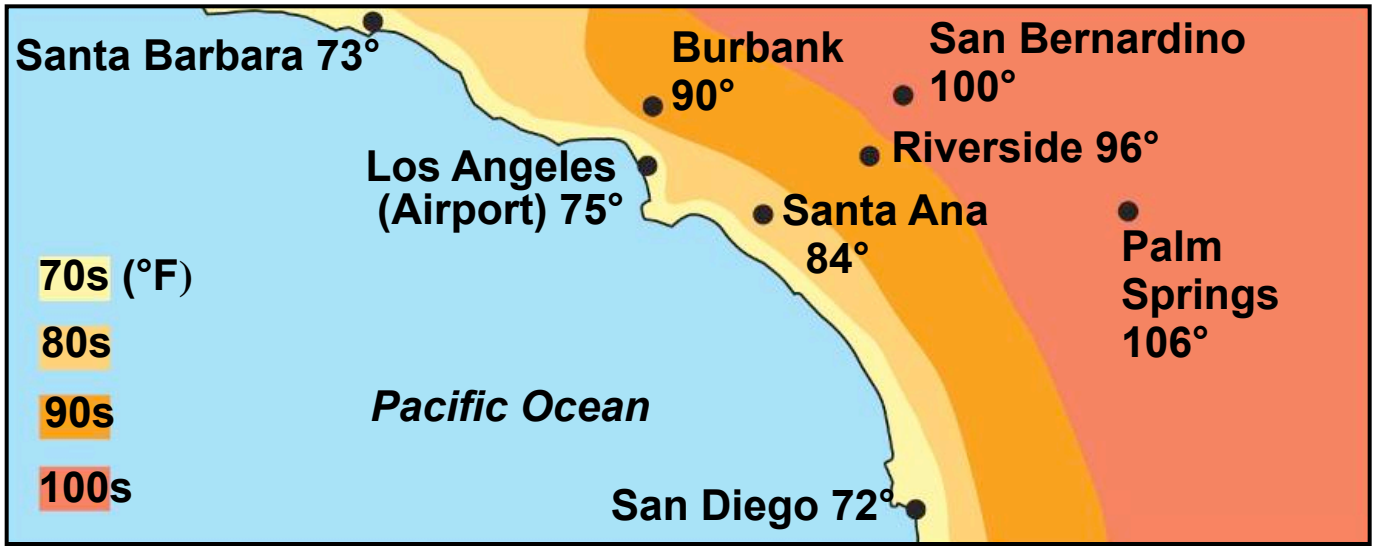
- H_2O resists changes in temperature
  - It has a high specific heat: 1cal/g/°C
    (It takes it takes 1 calorie of heat to raise 1 gram of water 1°C)
  - It can absorb a lot to heat from the warmer air
  - It can release a lot of stored heat to the cooler air

- H_2O moderates temperatures on Earth by absorbing and releasing heat
  - Cause of water's high specific heat: Hydrogen Bonding



How does Hydrogen Bonding contributed to water's high specific heat?

- When heat is absorbed, hydrogen bonds break.
  - Heat can be absorbed with little change in temperature (average kinetic energy) because the energy is used to break hydrogen bonds before it can cause the water molecule to start moving faster.
- Heat is released when hydrogen bonds form
  - Large amounts of of energy is released as heat when even small amounts of new hydrogen bonds form as heat transfers out of water, which causes the the temperature of water to drop slightly.
- Water helps moderate temperatures that allow for life

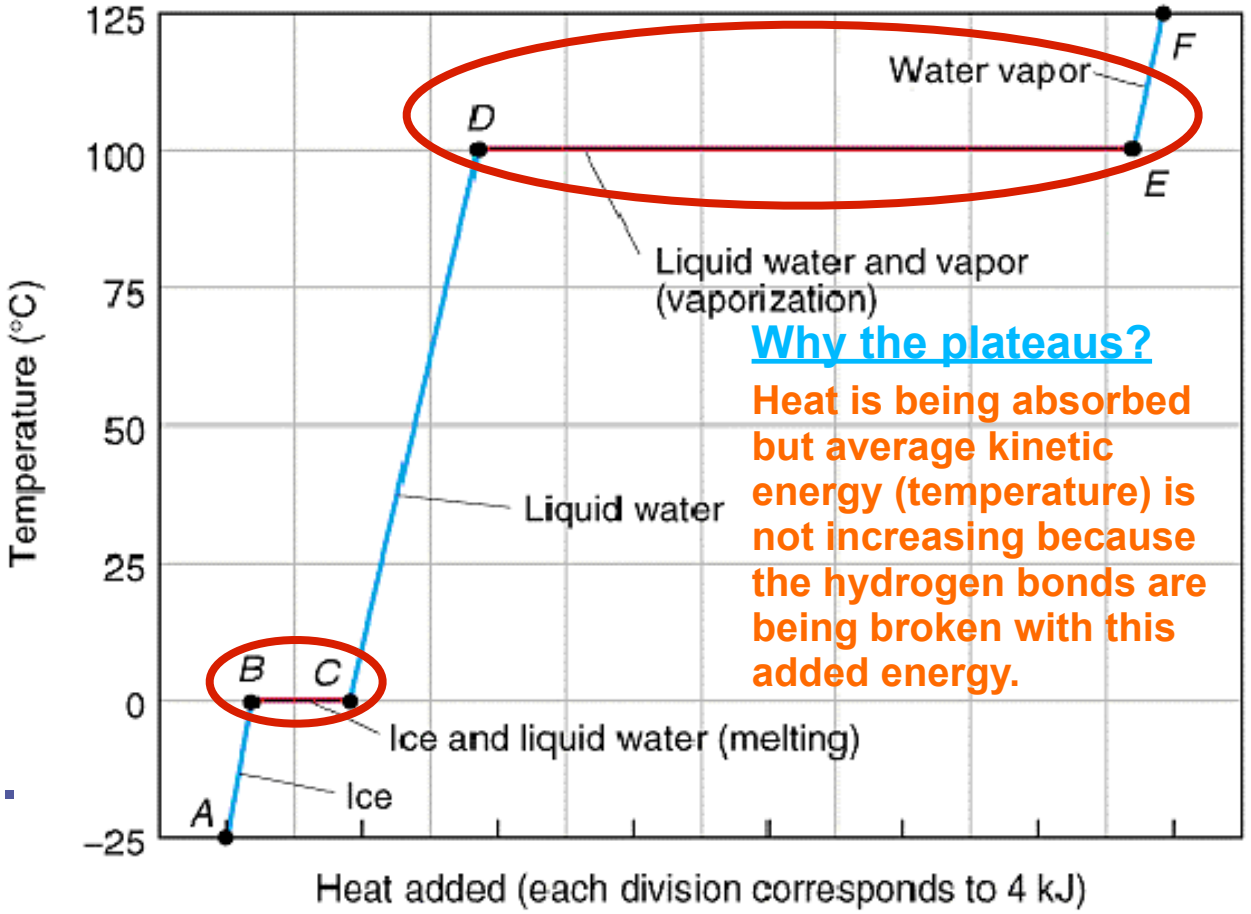


2. Heat of vaporization

- **Evaporation** = the process in which a substance transforms from a liquid to a gas

- **Heat of vaporization** = the heat a liquid must absorb for 1 g to be converted to gas.

To evaporate 1 g of water at 25°C, 580 cal of heat is needed.

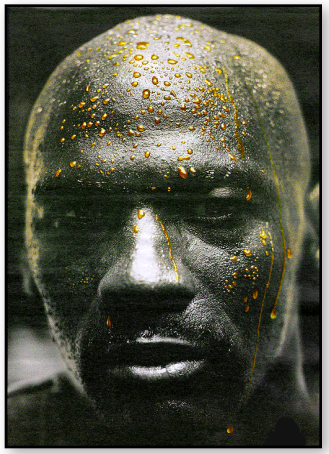


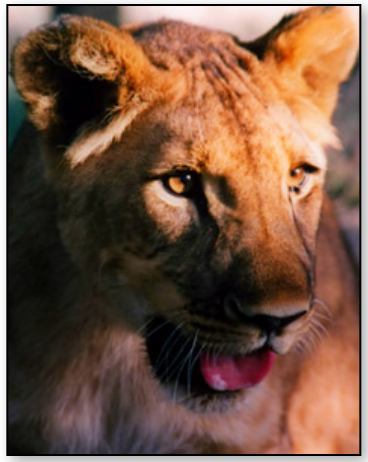
Why the plateaus?

Heat is being absorbed but average kinetic energy (temperature) is not increasing because the hydrogen bonds are being broken with this added energy.

2. Heat of vaporization

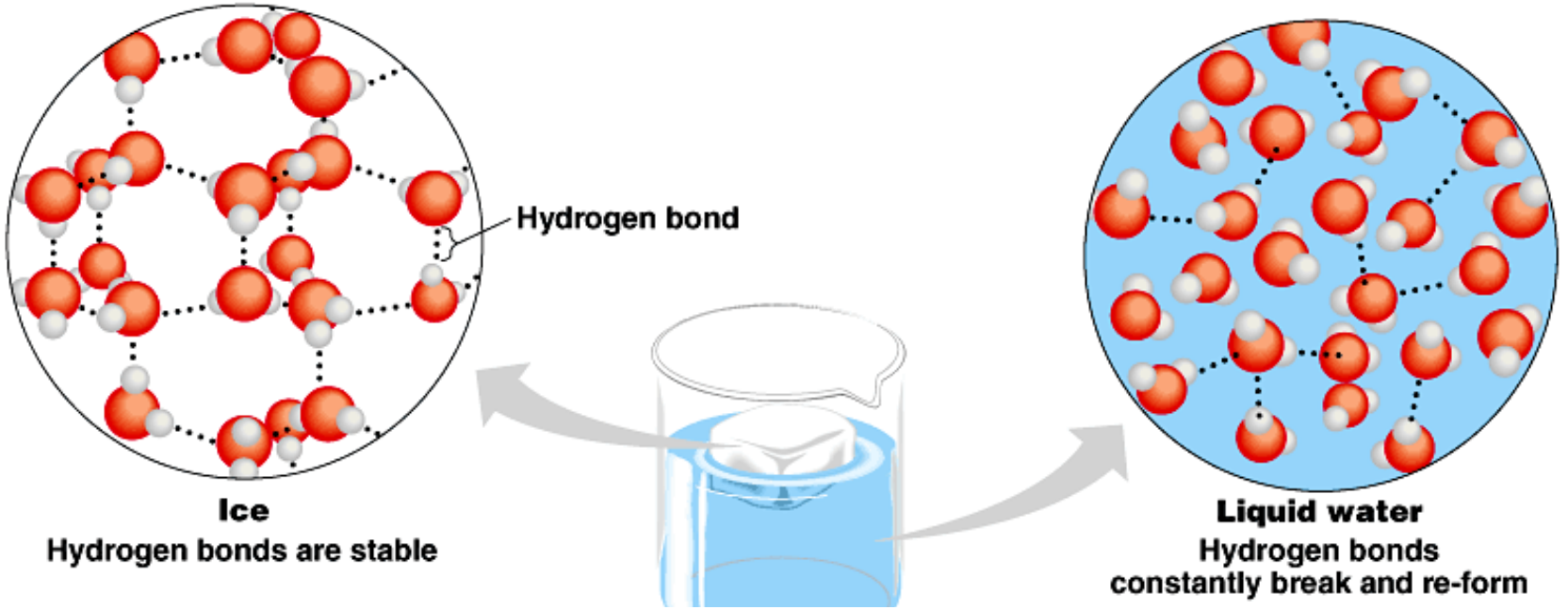
- Evaporative cooling of water helps stabilize temperatures in organisms and bodies of water
- As a liquid evaporates, its remaining surface cools, a process called EVAPORATIVE COOLING
  - For water molecules to escape from liquid into gas, heat must be absorbed in order to break the hydrogen bonds within the liquid.
    - *Heat transfers from warmer substance to cooler substances - so from the cells doing energy processing, to the interstitial fluid surrounding the cells, to the blood, and then to the cooler aqueous liquid secreted onto the surface of parts of the body.*
  - The molecules with the fastest kinetic motion/highest amounts of kinetic energy escape into the air.
  - The average kinetic energy (and temperature) of the remaining liquid water thus drops.
    - This process occurs over and over as more liquid water is secreted onto the body surface, absorbs more heat from the body's warmer surface, causing the kinetic energy in the secreted liquid to rise, resulting in eventual evaporation.
  - The body is cooled as the water absorbs heat and leaves the surface of the body.





3. Ice, the insulator.

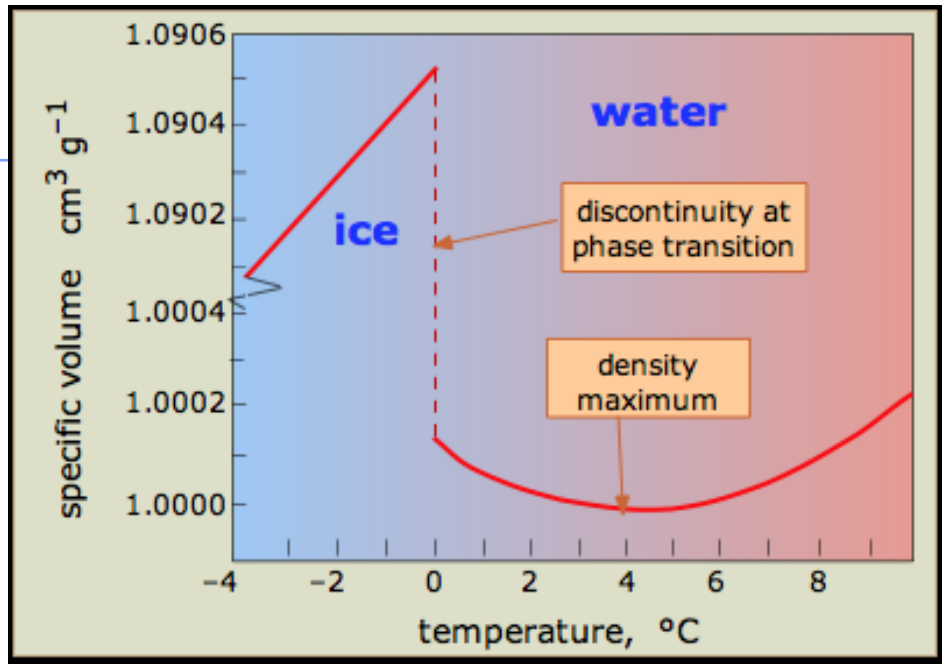
- Substances are usually more dense when they are solid, but not water!
- While other materials contract when they solidify, ice expands below 4°C. Ice floats!
  - Water forms a 3-D crystalline lattice in which each H_2O molecule is hydrogen bonded to 4 neighboring H_2O molecules
    - Ice is 10% less dense than water at 4°C.



Why is floating ice important?

Oceans & lakes don't freeze solid!

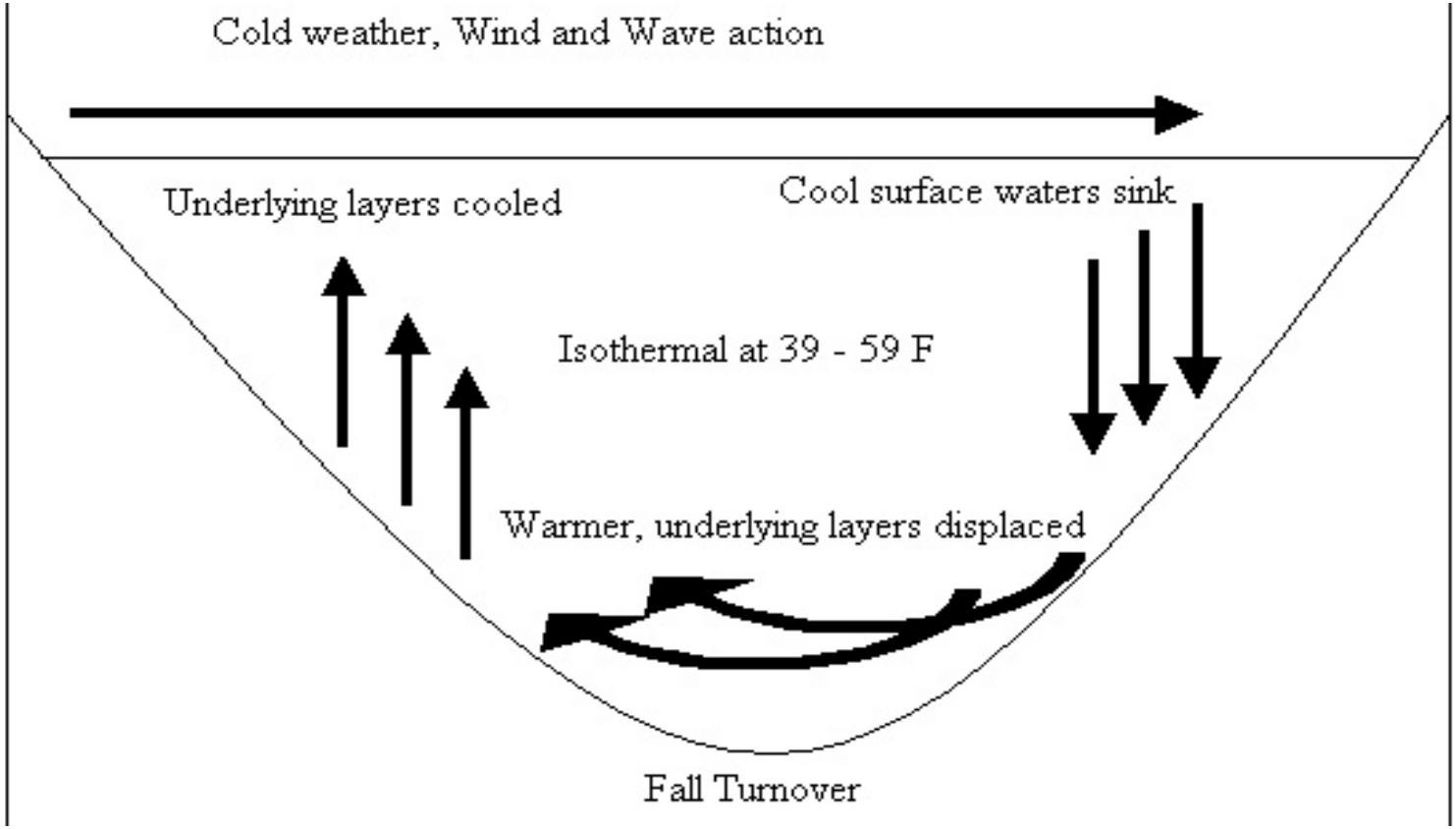
- Surface ice insulates the water below in the winter
  - Allows life to survive the winter
  - If ice sank…
    - In the winter, ponds, lakes & oceans would freeze solid.
    - In the summer, only upper few inches would thaw.



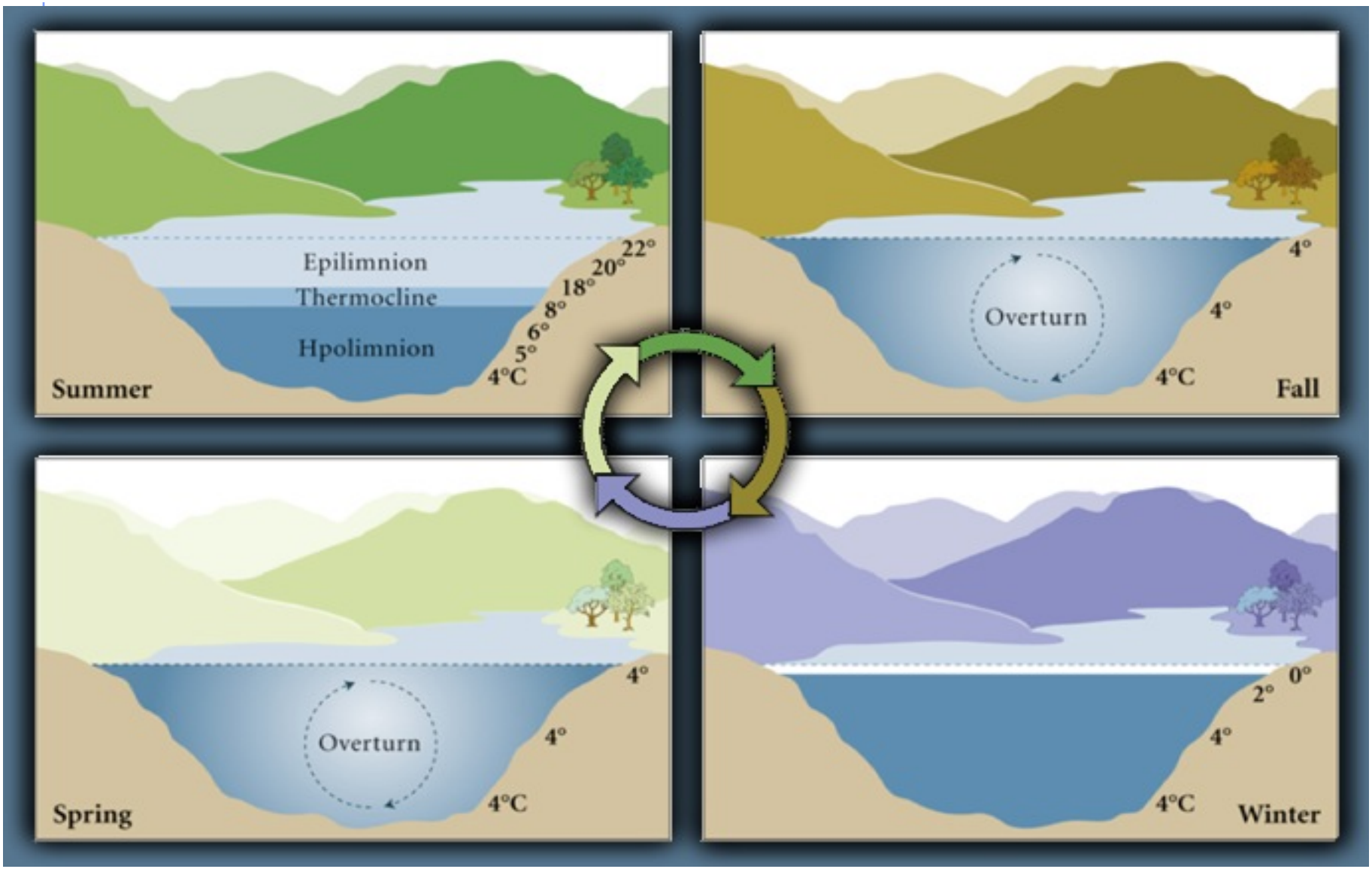
http://www.chem1.com/acad/sci/aboutwater.html

Why is floating ice important?
It ensures that oceans & deep lakes don't freeze solid!

- **Water's movement caused by changes in air temperatures leads to the seasonal turnover of lakes**
  - **In the fall and the spring: Sinking cold liquid surface H_2O, which is more dense at temperatures right above 4ºC compared to the warmer water deeper in the body of water, helps mix into the body of water inorganic and organic nutrients that accumulate at the bottom during summer and winter times and helps bring oxygen gas diffusing into the top surface of the water into the deeper waters.**



The Seasonal Behavior of Water



http://www.triplepointwater.com/blog/images/Turnover.jpg

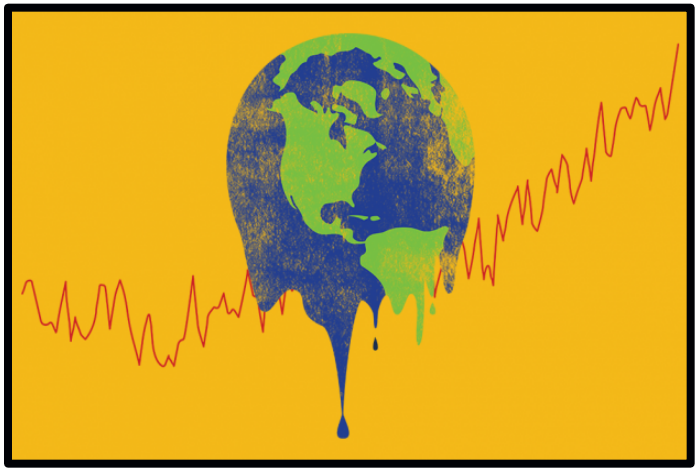
The consequences of Atmospheric Warming on Sea Level Rise

As humans continue to pour greenhouse gases like CO2 into the atmosphere, more solar energy is trapped by our atmosphere causing increased global warming.

- **The world's seas have absorbed more than 90% of the solar heat absorbed by these atmospheric gases.**

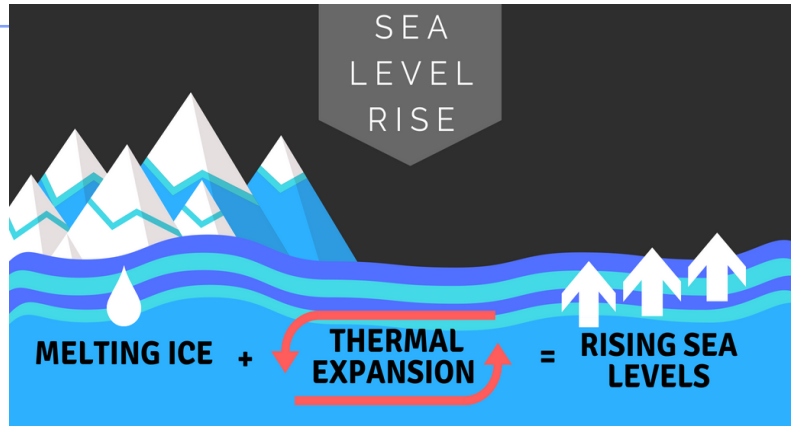
Scientists use the term CLIMATE CHANGE when describing the complex shifts affecting our planet's weather and climate systems, which include more than just global temperature rise.

- **Rising seas is one of those climate change effects.**
  - **Average sea levels have swelled over 8 inches (about 23 cm) since 1880, with about three of those inches gained in the last 25 years.**



The consequences of Atmospheric Warming on Sea Level Rise

Every year, the sea rises another 0.13 inches (3.2 mm). Why?

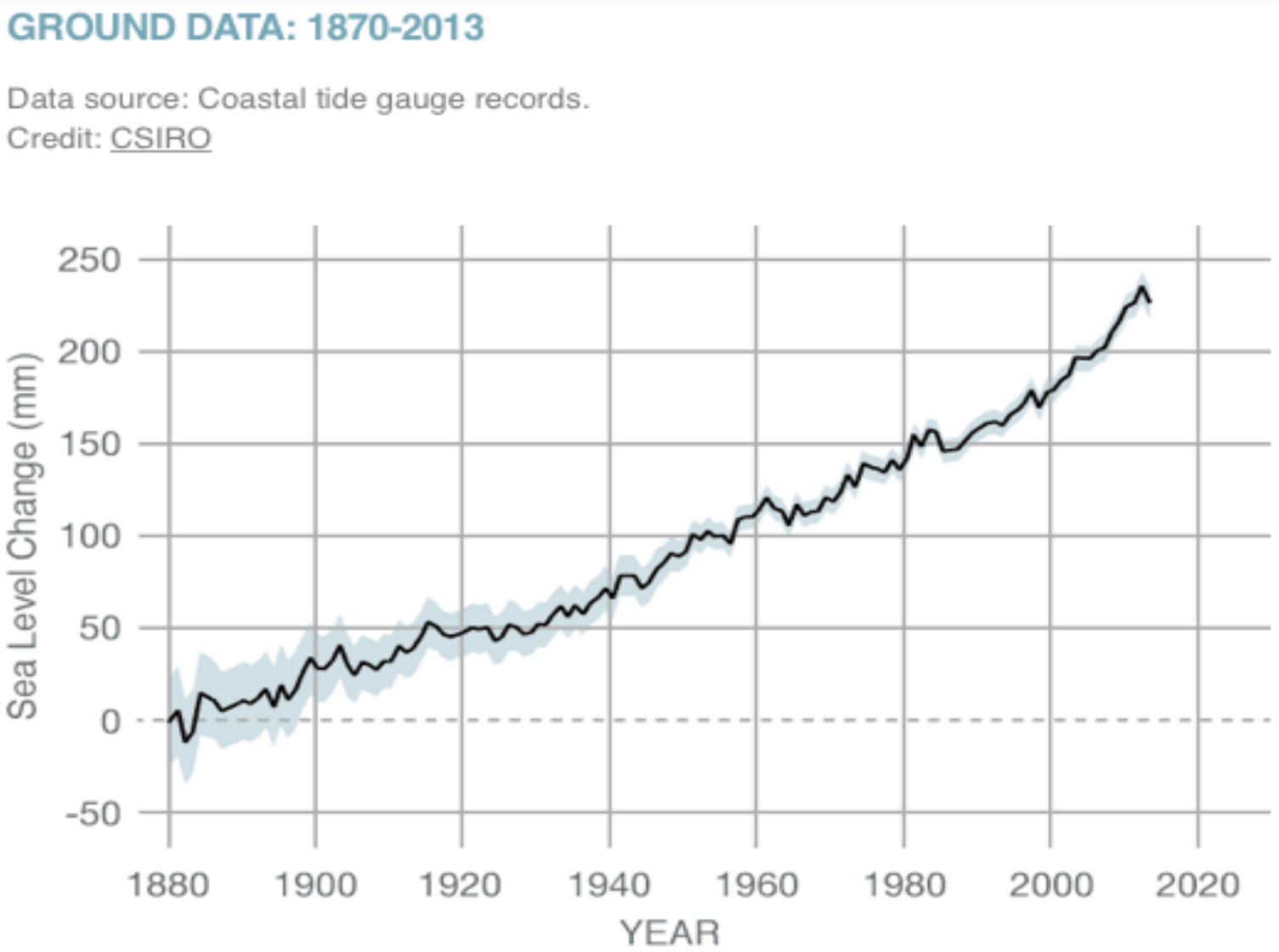


1. **Thermal expansion: When water heats up, it expands.**
   - **~50% of sea-level rise over the past 25 years is attributable to warmer oceans simply occupying more space.**

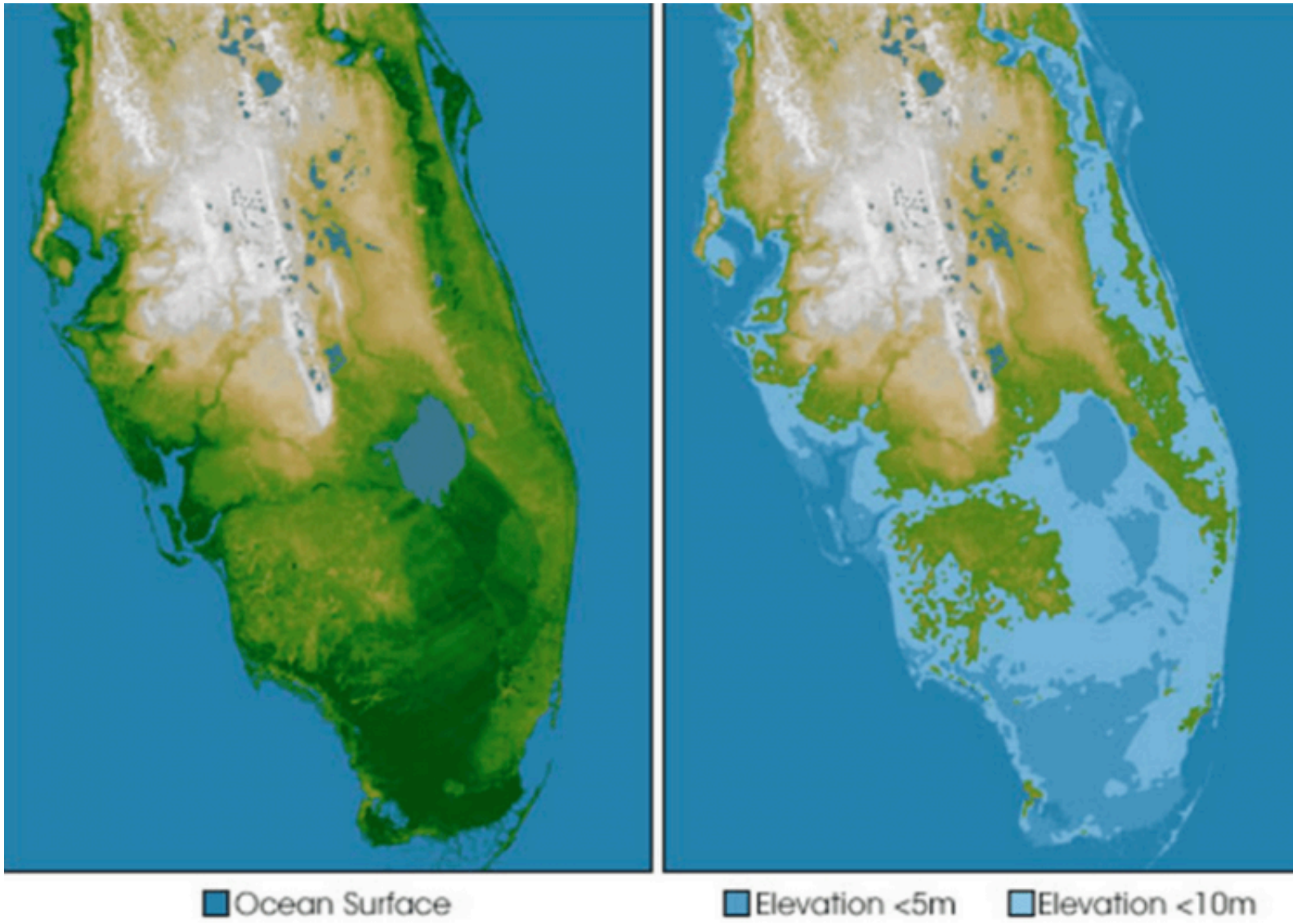
2. **Melting glaciers: Persistently higher temperatures caused by global warming have led to greater-than-average summer melting as well as diminished snowfall due to later winters and earlier springs.**
   - **An imbalance is created between runoff due to melting & ocean evaporation that returns water to the glacier via snowfall, causing sea level rise.**

3. **Loss of Greenland and Antarctica's ice sheets: Increased heat is causing the massive ice sheets that cover Greenland and Antarctica to melt more quickly.**
   - **Scientists also believe that meltwater from above and seawater from below is seeping beneath ice sheets, effectively lubricating ice streams and causing them to move more quickly into the sea.**

The consequences of Atmospheric Warming on Sea Level Rise



The consequences of Atmospheric Warming on Sea Level Rise



The consequences of Atmospheric Warming on Sea Level Rise

Sea level increase can cause:

- Destructive erosion
- Wetland flooding

Disruptive & expensive nuisance flooding is 300-900% more frequent within U.S. coastal communities than it was just 50 years ago.

- **In the U.S., ~40% live in relatively high-population-density coastal areas & globally, 8 of the 10 largest cities are near a coast.**

- Aquifer and agricultural soil contamination with salt water
- Lost habitat for fish, birds, & plants.
- More dangerous hurricanes and typhoons that move more slowly and drop more rain, contributing to more powerful storm surges that can have devastating effects on habitats further inland and cause deaths.

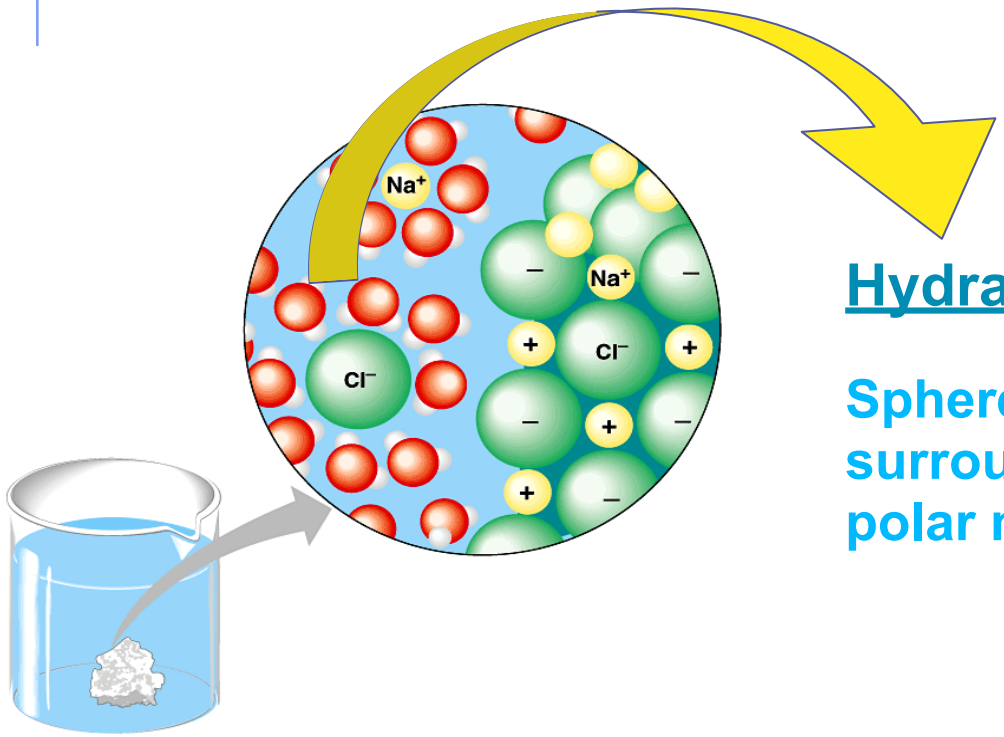
- **One study found that between 1963-2012, ~50% of all deaths from Atlantic hurricanes were caused by storm surges.**
  - **Storm surge = temporary abnormal rise of water generated by a storm, over and above the predicted astronomical tides.**
- **Flooding in coastal areas is forcing people to migrate to higher ground**

Millions are vulnerable from flood risk & other climate change effects.

- **Infrastructure damage threatens country's economies**
- **Even basic services such as Internet access is threatened, much of the underlying communications infrastructure under ground**

4. Water is the Solvent of Life

- Polarity makes H_2O a good solvent
  - Polar H_2O molecules surround + & – ions or partially charges molecules through ion-dipole forces
    - Solvents (dissolving agents) dissolve solutes (the substances that are dissolved) creating solutions (homogeneous mixtures of two or more substances)

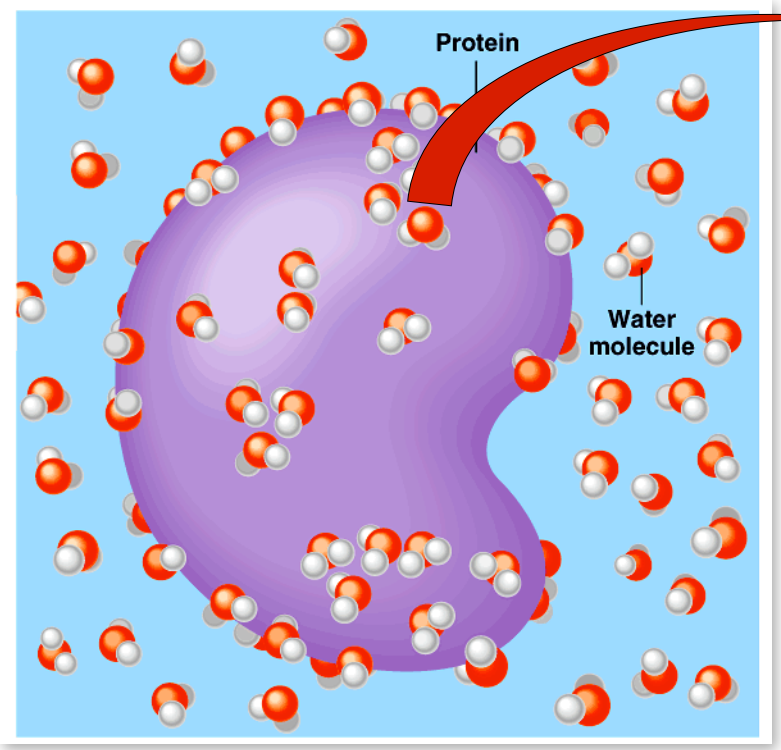


Hydration shells:

Sphere of water molecules that surround each dissolved ions or polar molecule.

What dissolves in water?

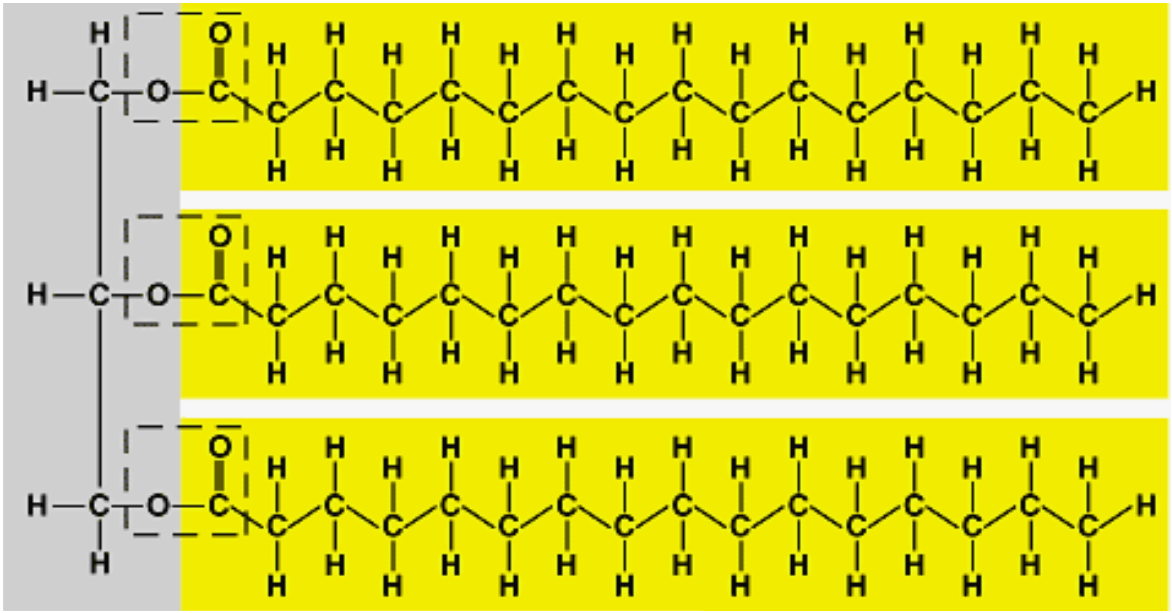
- **Hydrophilic** (Greek roots ***hydro***, water, and ***philos***, friend of) **Substances**
  - Substances that experience an attraction to H_2O
  - Are these **polar** or **non-polar**?



Partial charges on surface of large molecules like proteins hydrogen bond with the partial charges on the water molecule.

What doesn't dissolve in water?

- **Hydrophobic** (From Greek, *Phobos*, fearing) **Substances**
  - Substances that don't experience an attraction to H_2O
  - **Polar** or **non-polar**?
    - These cannot form hydrogen bonds.



fat (triglycerol)

http://www.biojobblog.com/uploads/image/oil-and-water(1).jpg

Give it a try… "Properties of Water"

Predict how life on earth would be different if water were *less* polar. Which one of the following would result if organisms lived in and consisted of a less polar medium than water?

A. Heavier insects than water striders would be able to walk on the surface of a pond.

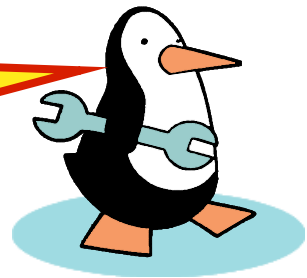
B. Increased cohesion would contribute to increased upward water transport in plants.

C. The water temperature of ponds and pools would increase more slowly when in sunlight.

D. Sweating would be a less effective means of keeping cool.

E. More salts would go into the solution in blood and body fluids.

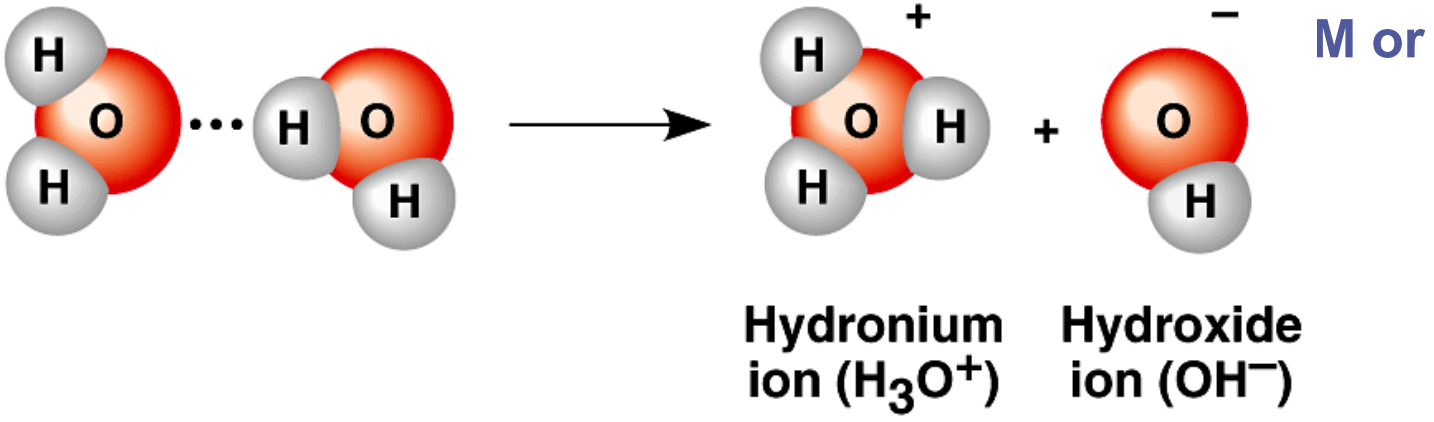
The sweat would absorb less thermal energy before the molecules evaporate off the skin with weaker or no hydrogen bonding…



Ionization of Water

- **Some water ionizes**
  - H^+ splits off from H_2O, leaving behind a OH^-

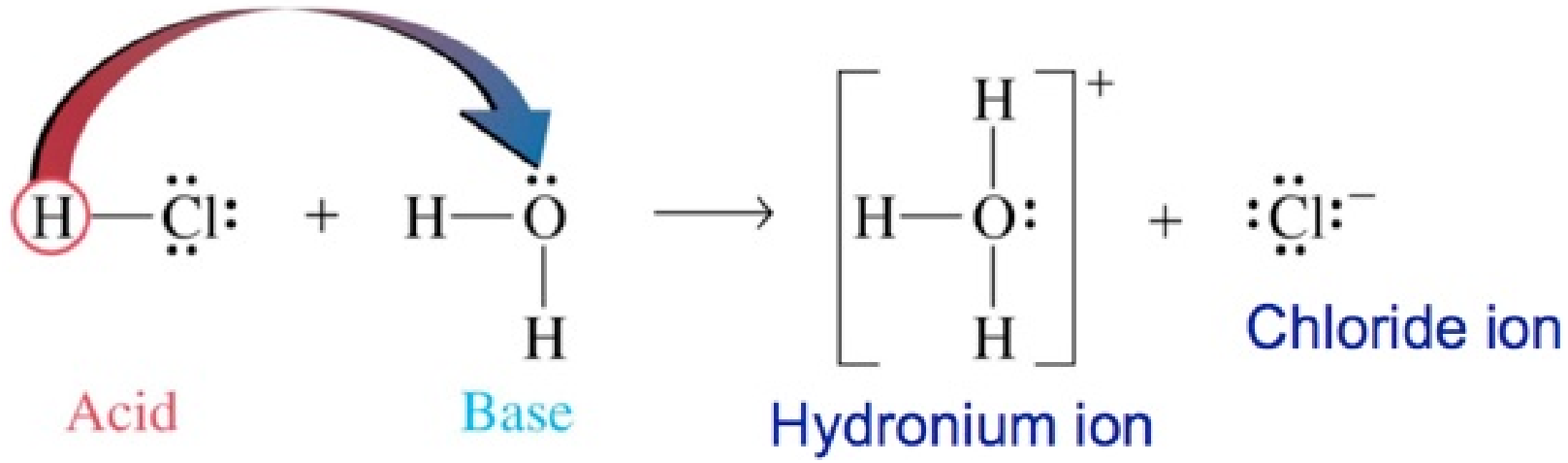
$$H_2O \rightarrow H^+ + OH^-$$

    - In reality, hydrogen ions do not exist on its own.
  - In water, one water molecule donates a proton (H^+) to another to produce hydronium ion (H_3O^+) and hydroxide ion (OH^-) which means that water can behave as both an acid and a base.
  - 

M or

Acids & Bases

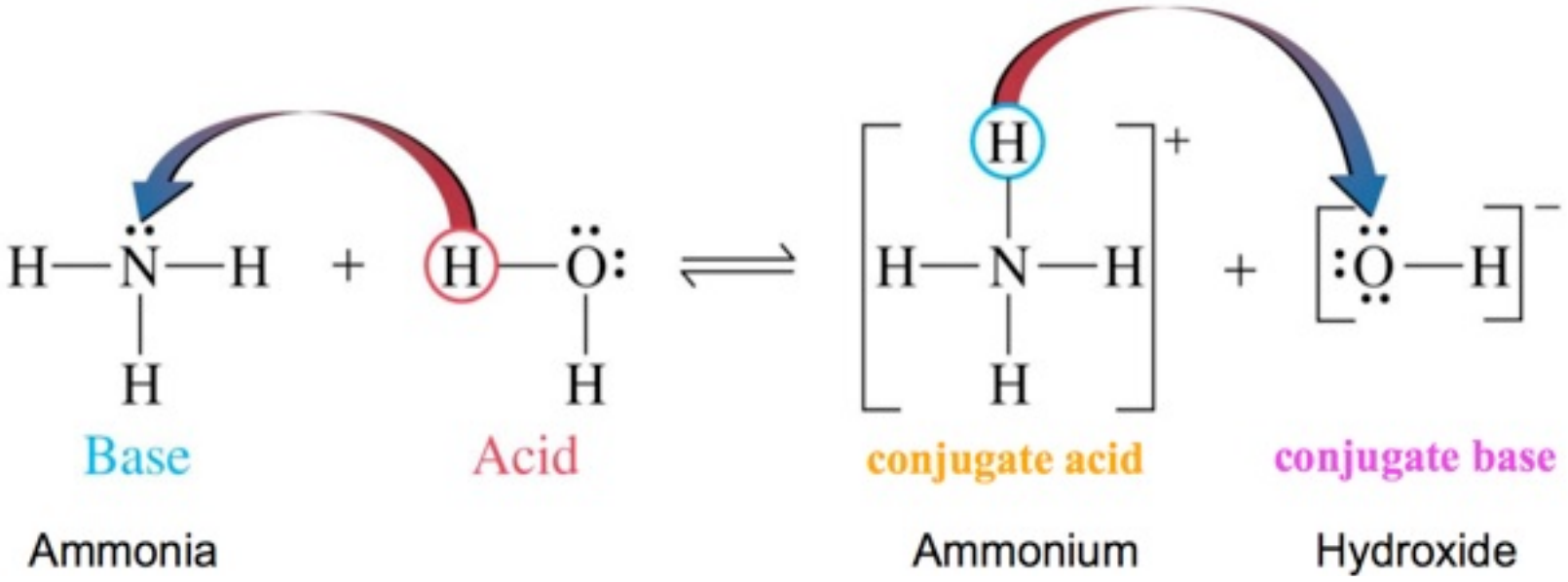
- Some substances, when added to water, can alter the concentration of H+ present in pure water
- **Acid**
  - A substance that increases the hydrogen ion concentration of a solution.



Acids & Bases

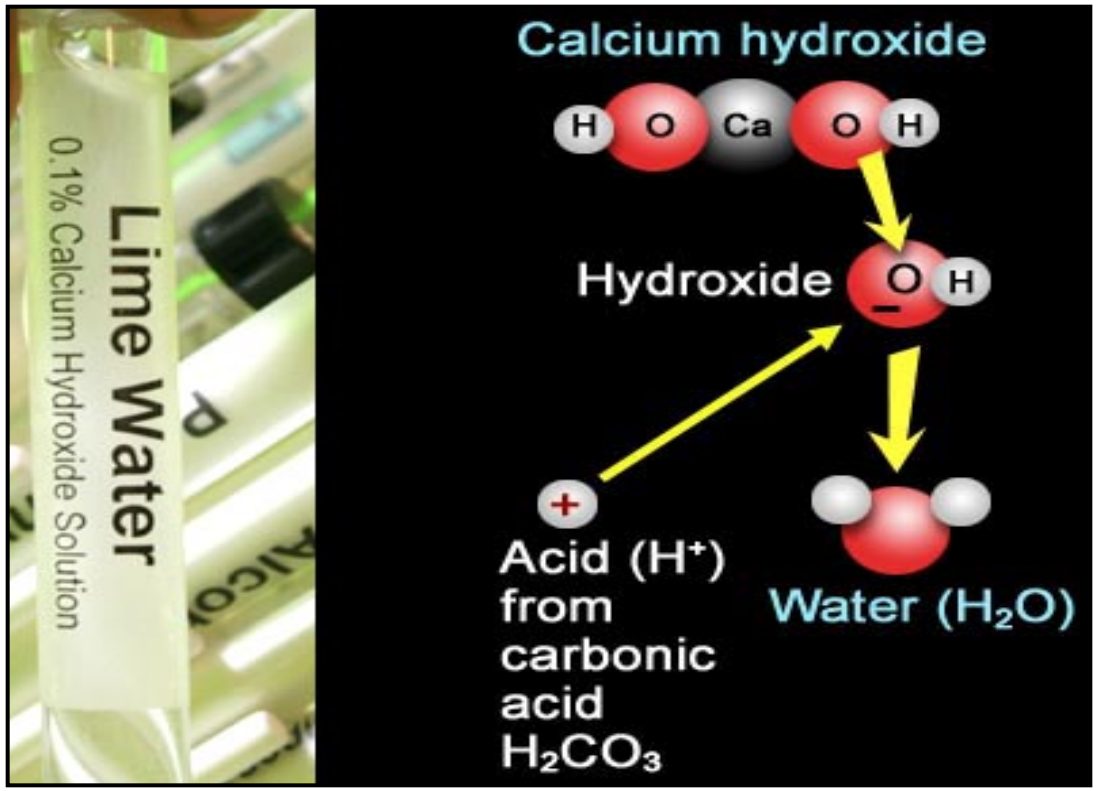
- **Base**
  - **A substance that reduces the hydrogen ion concentration of a solution.**
    - **Bases affect [H+] in two ways:**

1. **Can do so directly by accepting hydrogen ions.**



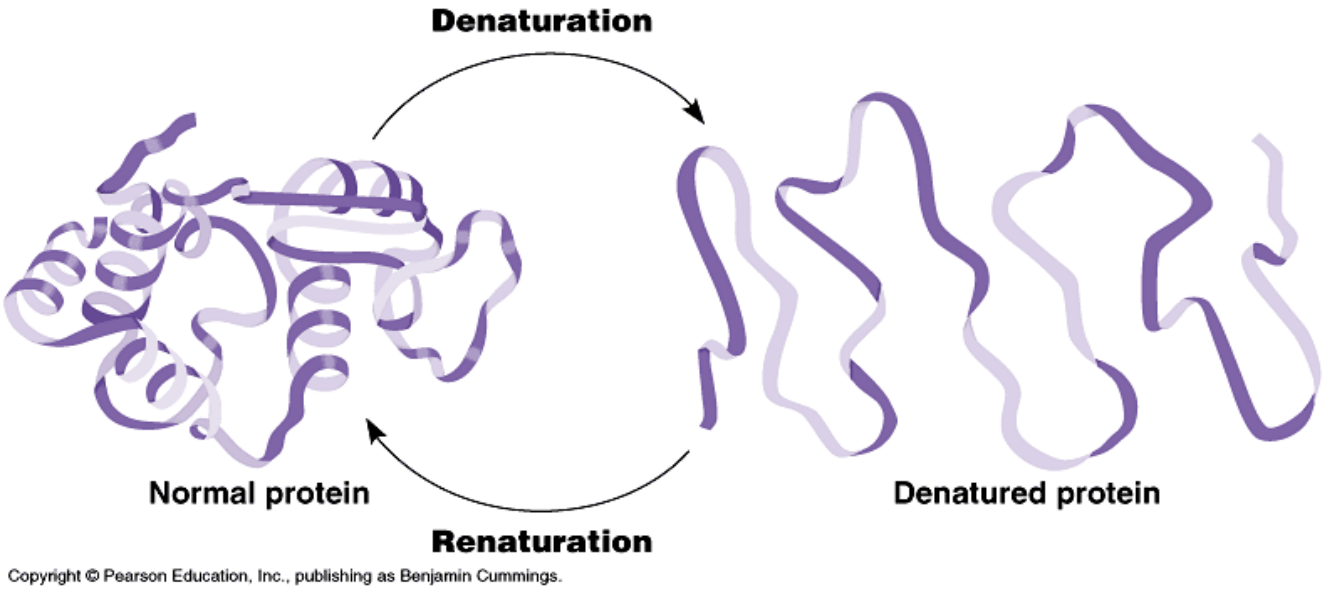
Acids & Bases

2. **Can do so indirectly by dissociating to form hydroxide ions, which combine with hydrogen ions and form water.**



The pH Scale

- **pH is CRITICAL: A change in pH can alter molecular structure & functioning.**



  - if $[H^+] = [OH^-]$, the solution is neutral
  - if $[H^+] > [OH^-]$, the solution is acidic
  - if $[H^+] < [OH^-]$, the solution is basic

The pH Scale

- Concentration of H^+ and OH^- is 10^{-7} M **each** in neutral water.

  (**Molarity** = # moles of solute / liter of solution)
  (**Molar concentration** is indicated by [ ])

  - Their product is a constant $[H^+]\,[OH^-] = 10^{-14}$

    (If H+ ions increase, OH- will decrease because some will combine with the H+ to make water. Similarly, if OH- increases, H+ will decrease because some will combine to form water as well).

  - If one goes up in concentration the other must go down & vice versa!

- The concentration of both ions can vary by a factor of a 100 trillion so for convenience a different system was devised to express their levels not based on moles/L

The pH Scale

- pH = The negative logarithm (base 10) of the hydrogen ion concentration.

$$pH = -\log_{10}[H^+]$$

- pH scale tells us how acid or basic solution is
  - 1 acidic → 7 neutral → 14 basic

http://www.worsleyschool.net/science/files/pH/phscale.gif

pH Scale

Each step represents a tenfold change in $[H^+]$

pH 1 → pH 2

$10^{-1} \rightarrow 10^{-2}$

1/10 → 1/100

10 times less H^+

pH 8 → pH 6

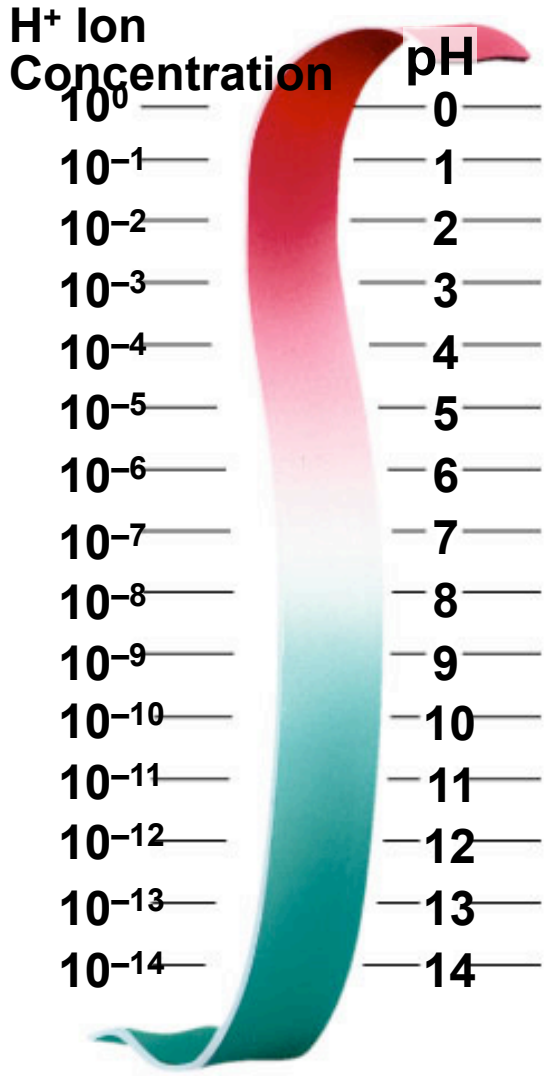
$10^{-8} \rightarrow 10^{-6}$

100 times more H^+

pH 11 → pH 8

$10^{-11} \rightarrow 10^{-8}$

1000 times more H^+



Examples of Solutions

Hydrochloric acid

Stomach acid, Lemon juice

Vinegar, cola, beer

Tomatoes

Black coffee, Rainwater

Urine, Saliva

Pure water, Blood

Seawater

Baking soda

Great Salt Lake

Household ammonia

Household bleach

Oven cleaner

Sodium hydroxide

Buffers & pH Controls

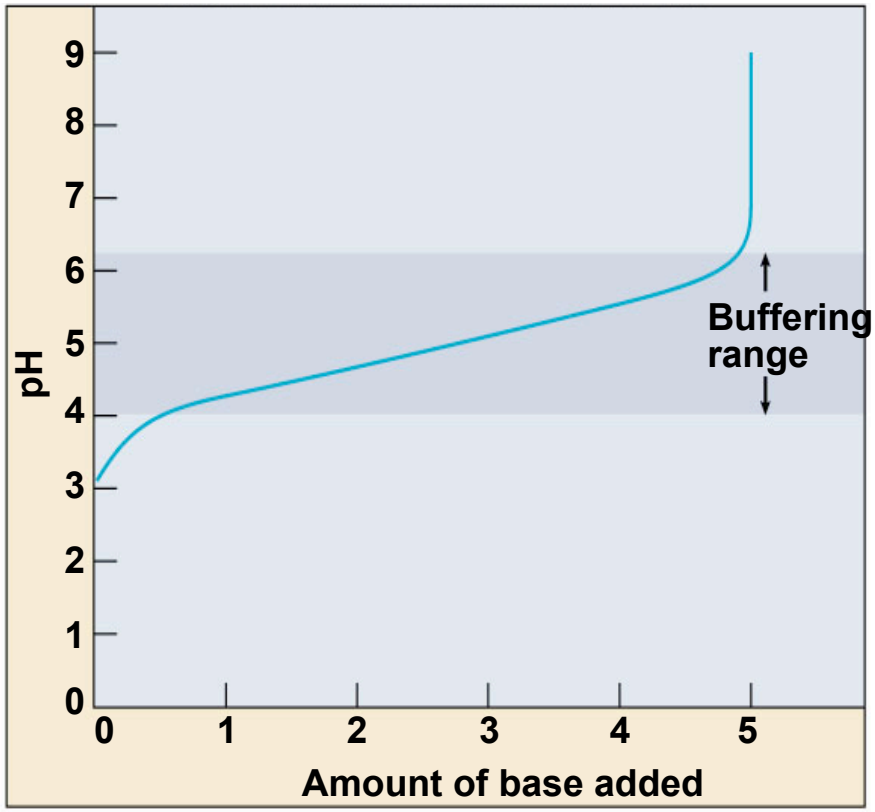
- pH of cells must be kept ~7
  - pH affects shape of molecules
  - Shape of molecules affect function
  - Therefore, pH affects cellular function

- pH is controlled with?

  Buffers:

  Substances that minimize changes in the concentrations of H+ and OH-

  - They serve as a reservoir of H^+
    - donate H+ when [H^+] falls
    - absorb H+ when [H^+] rises
  - Usually composed of a weak acid and its corresponding base.



Carbonic Acid-Bicarbonate Buffer in Blood

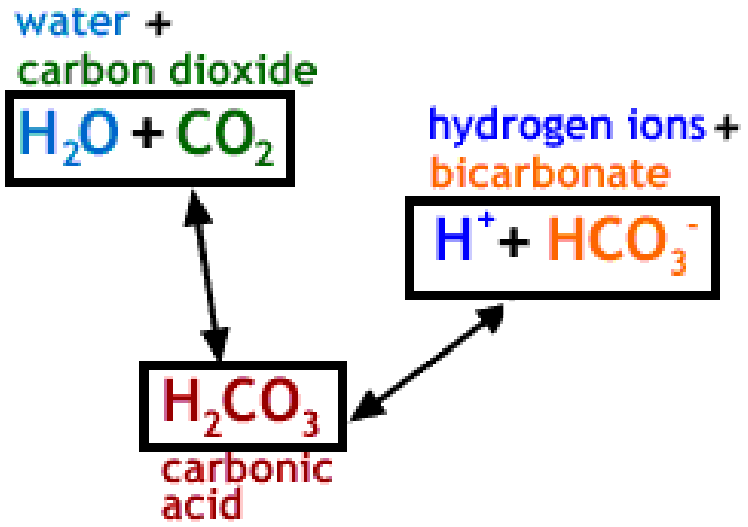
- **What happens as you exercise?**
  - **Muscles use up more O_2 as they convert the energy in the bonds of glucose into mechanical energy.**
  - **CO_2 is produced as a waste product which increases H^+ concentration.**
    - **Unless something is done, the pH in your blood would DROP!**
- **If the pH of the body gets too low (below 7.4), a condition known as acidosis results.**
  - **Protein-mediated reactions in the body are pH dependent and very sensitive to changes in pH**
  - **Blood pH must be be kept at 7.4**
    - **If the pH drops below 6.8 or rises above 7.8, death may occur.**

Carbonic Acid-Bicarbonate Buffer in Blood

- **Fortunately, we have buffers in the blood to protect against large changes in pH.**
  - **The bicarbonate buffering system maintains acid-base homeostasis in animals, keeping blood plasma pH constant.**

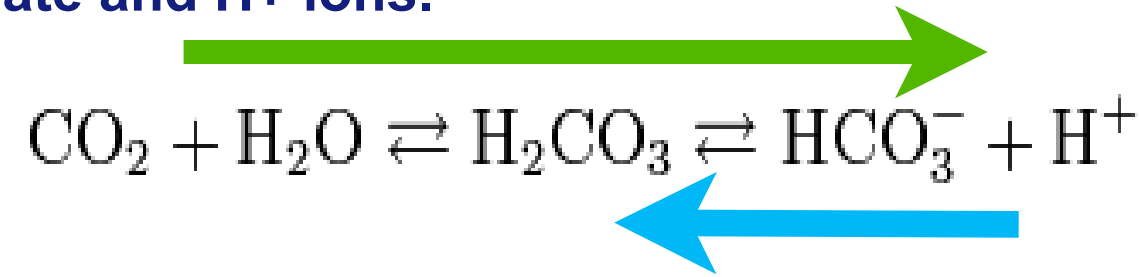
$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

- **Any disturbance of the system will be compensated by a shift in the chemical equilibrium according to Le Chatelier's principle.**



Carbonic Acid-Bicarbonate Buffer in Blood

- When blood accumulates excess CO_2 during exercise, and if the blood had no buffer, the forward reactions would be favored, which would result in more H+ ions forming: carbon dioxide reacts with water to form carbonic acid, which decomposes into bicarbonate and H+ ions.



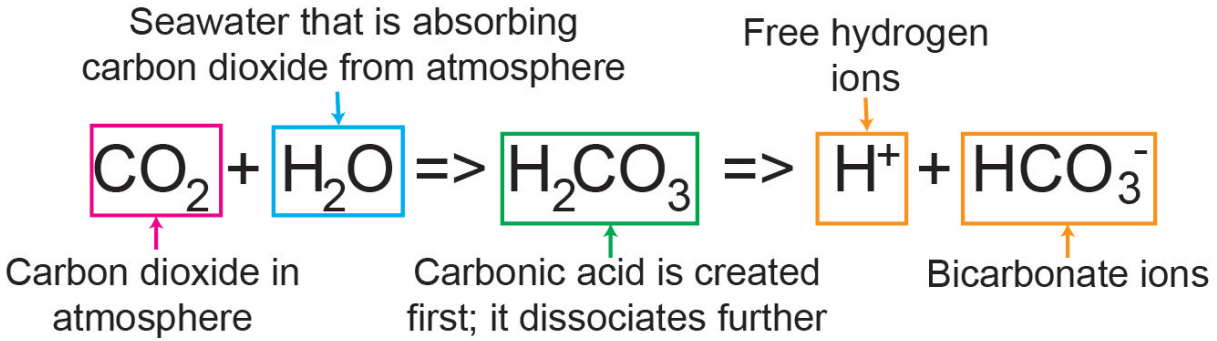
$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows HCO_3^- + H^+$$

  - However, because we already have bicarbonate ion in our blood, some of these extra H+ ions associate with the extra bicarbonate ion already present in the blood and body fluids, which favors the second chemical reaction occurring in reverse. This results in the reforming of some carbonic acid, decreasing the concentration of H+ again, resulting in a smaller net increase in acidity than otherwise would happen.

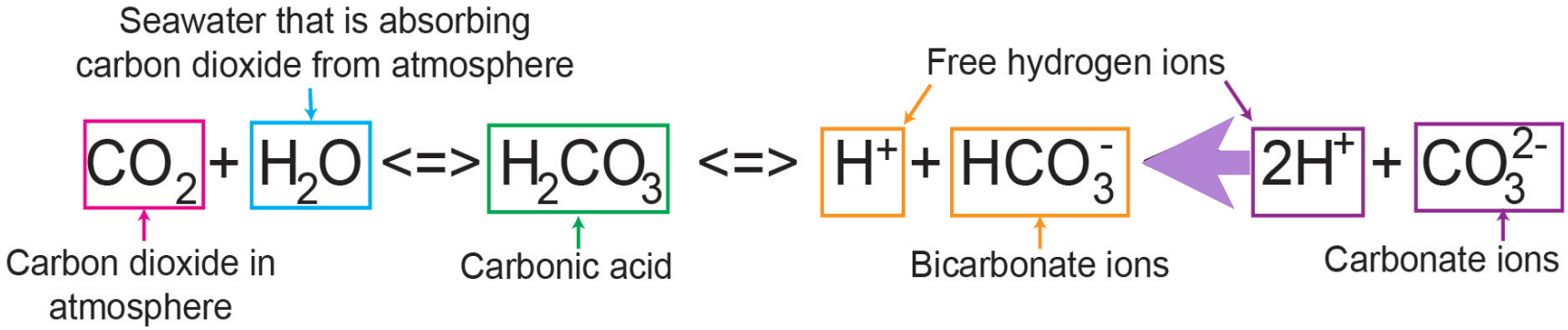
- Of course, you are also breathing to exhale the excess CO_2.
  - Exhaling excess CO_2 also causes both reverse reactions to be favored, which would further remove any additional accumulated H+

CO_2 level rise threatens our Environment by Altering pH of Rain & Bodies of Water

- **Acidification of bodies of water (lakes, oceans, rivers etc..) threatens aquatic life, a source of nutrients for many other organisms too**

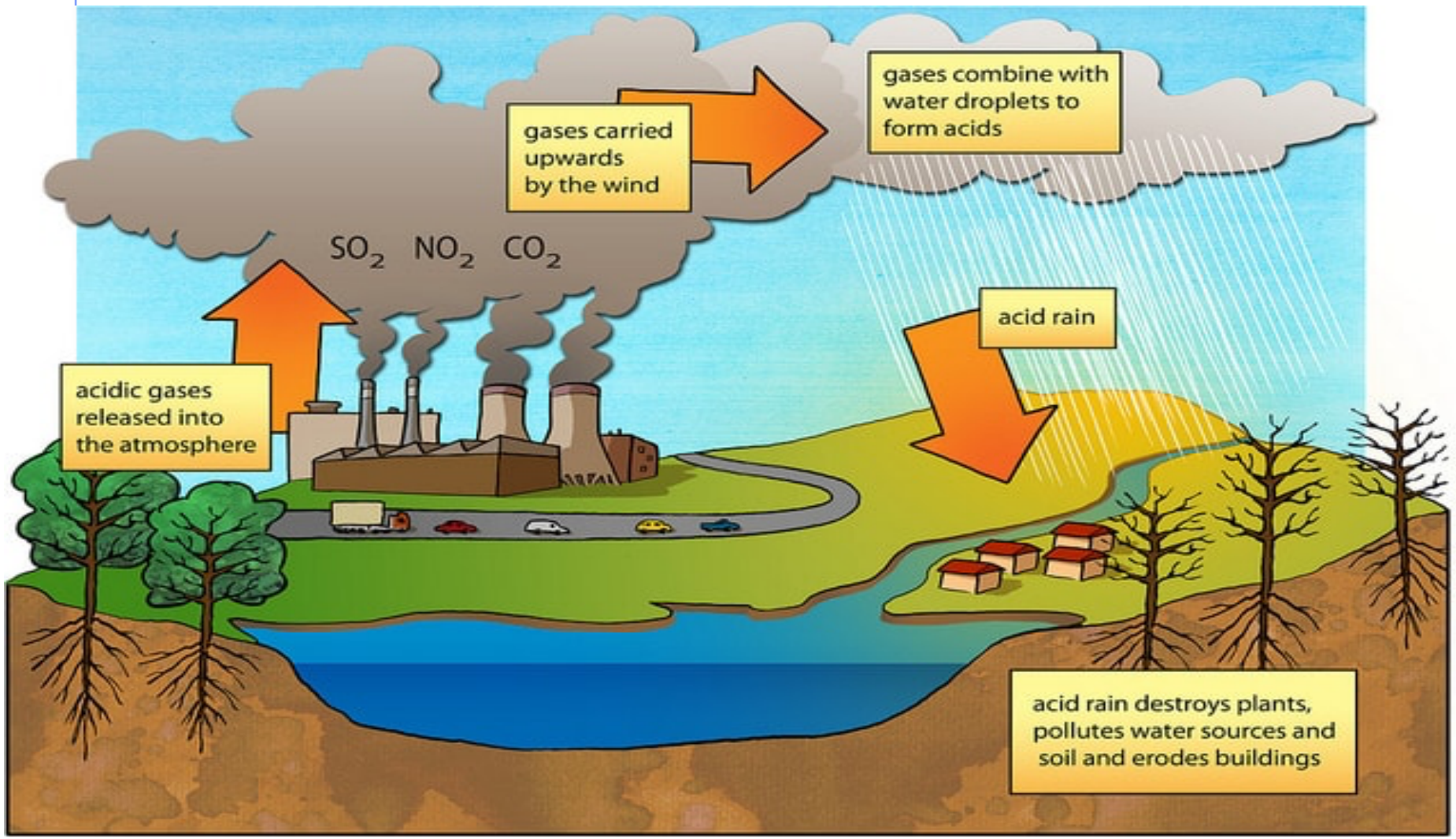


- **Increased H+ due to added CO_2 also react with Carbonate Ions in water, reducing their concentration, harming corals and shell fish which need carbonate to make their calcium carbonate shells and coral bodies**

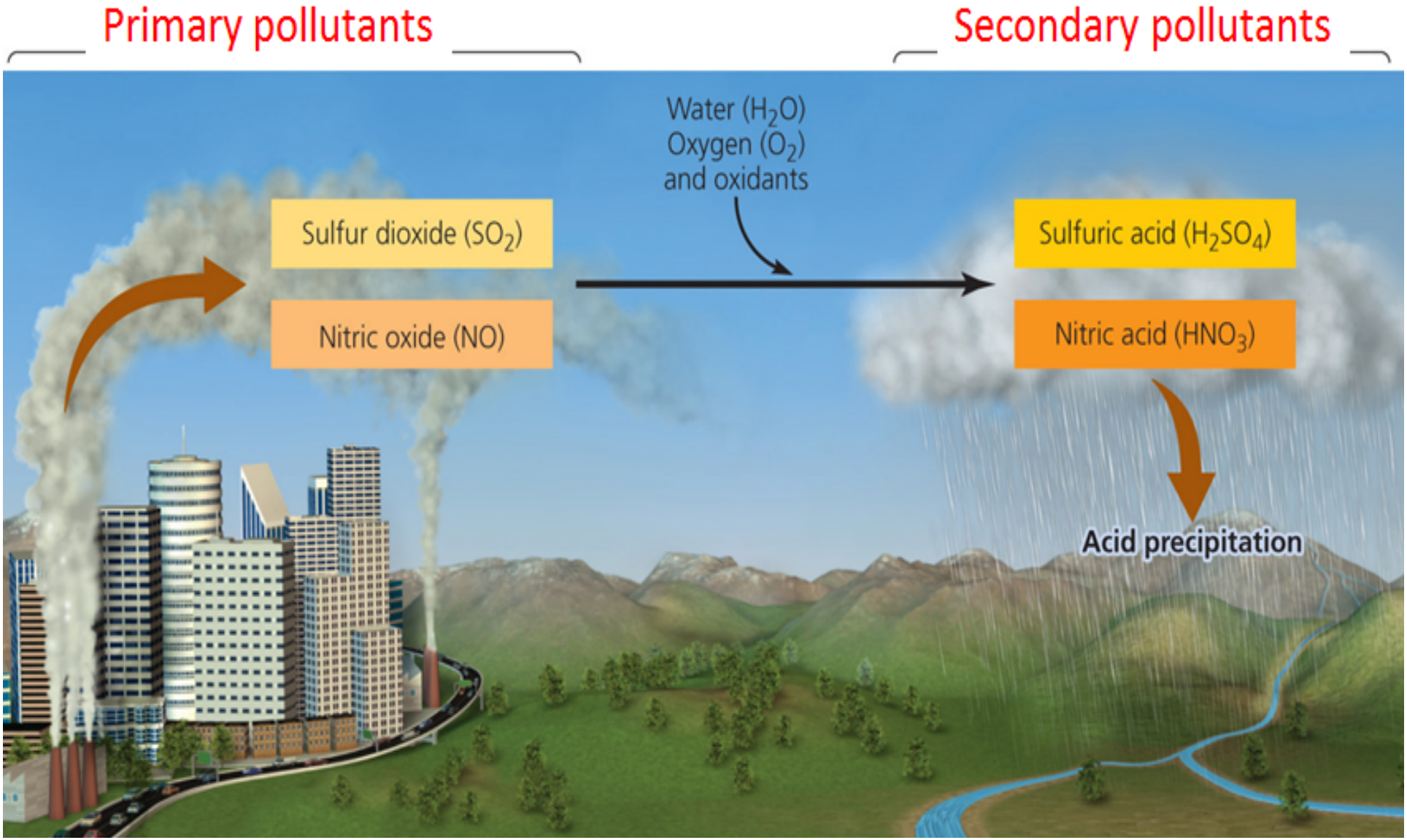


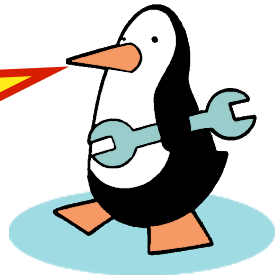
CO_2 level rise threatens our Environment by Altering pH of Rain & Oceans

- **Acidification of rain threatens living organisms**



Acid Rain Production





Do one brave thing today…then run like an Olympian!