Lecture 2- Chemistry for Biologists

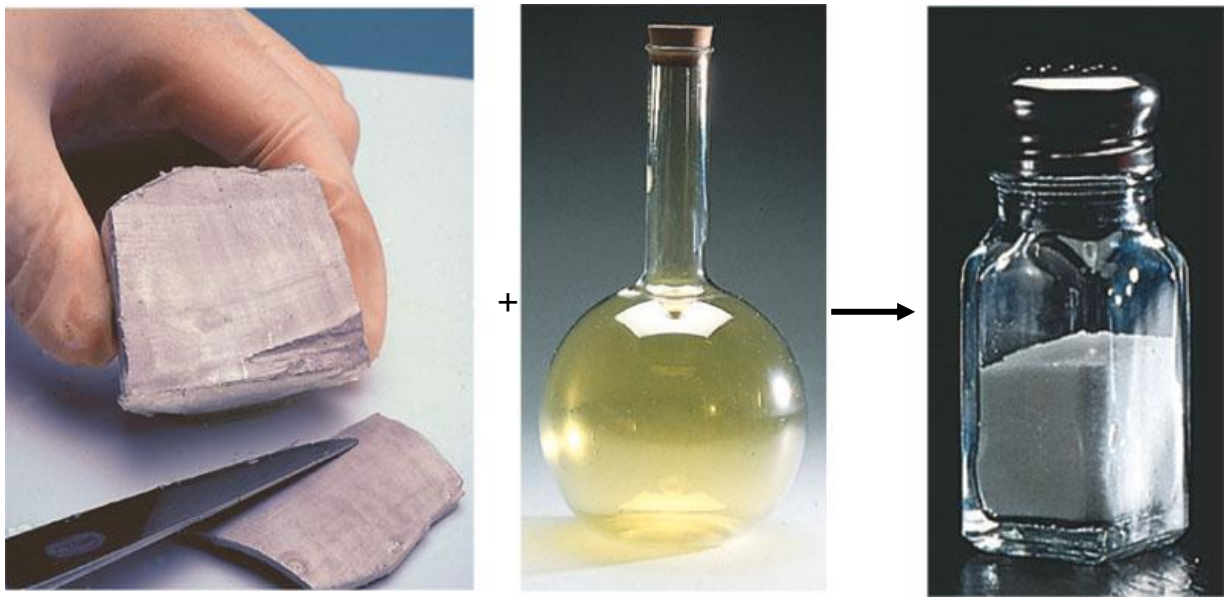
Elements and Compounds

- Organisms are composed of matter, which is anything that takes up space and has mass
- Matter is made up of elements, substances that cannot be broken down to other substances by chemical reactions

A compound

Is a substance consisting of two or more elements combined in a fixed ratio

Has characteristics different from those of its elements



Sodium Chloride Sodium Chloride

Chemical Elements of Life

Everything around you, living or non-living, solid, liquid, or gas, is made up of **chemical elements**.

There are at present at least **118 chemical elements.** Elements are chemical substances ("matter") made of **atoms**. **Life requires about 25 chemical elements**.

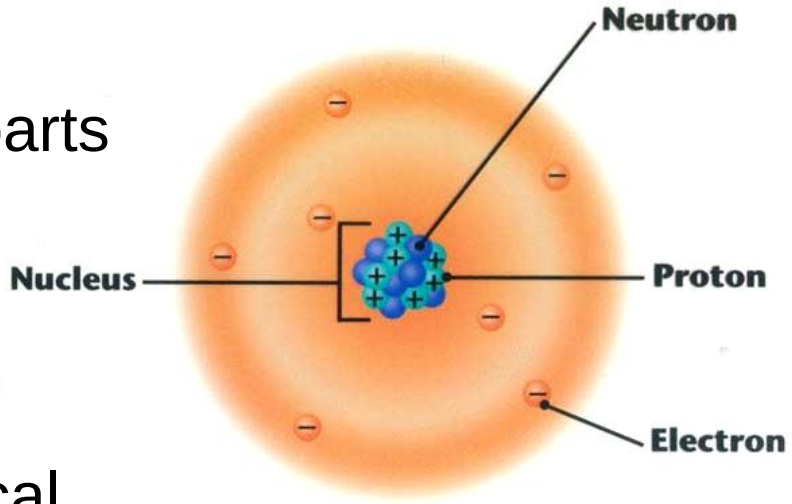
Essential Elements

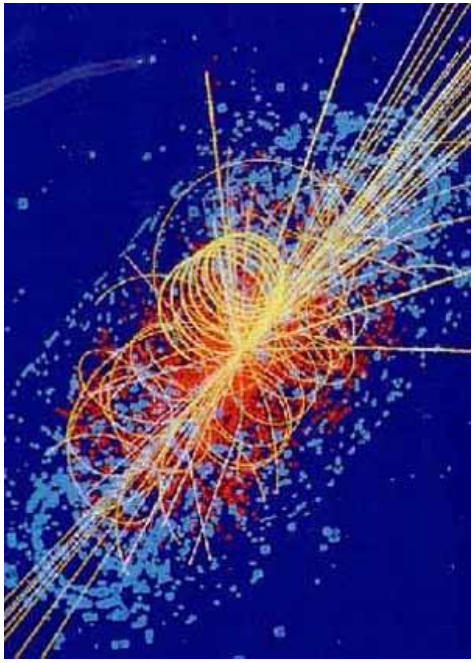
Carbon, hydrogen, oxygen, and nitrogen make up 96% of living matter

~**96%** of all living matter is made up of the chemical elements	~**4%** of all living matter is made up of the chemical elements	The remainder consists **"trace" elements** (needed in very small quantities only)
C = carbon, **O** = oxygen, **H** = hydrogen, **N** = nitrogen	**Ca** = calcium, **P** = phosphorus, **K** = potassium, **S** = sulfur **Na** = sodium, **Cl** = chlorine, **Mg** = magnesium	**Fe** = iron, **Mn** = manganese **Ni** = nickel, **Cu** = Copper **Zn** = zinc, etc - check out a vitamin bottle...

Subatomic Particles

- Atoms of each element
  - Are composed of even smaller parts called subatomic particles
- Relevant subatomic particles include
  - Neutrons, which have no electrical charge
  - Protons, which are positively charged
  - Electrons, which are negatively charged
- Protons and neutrons
  - Are found in the atomic nucleus
- Electrons
  - Surround the nucleus in a “cloud”





The number of protons and **neutrons identifies each element.** Each element has two "identification" numbers associated with it:

Atomic number (# of **p**): = the unique "identifier" of an element - the number of **protons**. This number does not vary for a particular atom!!! Remember that in an atom, **e** = **p**, so if you know the atomic number of an atom, you automatically know the number of electrons too.

Atomic Mass number (# of **p+n**): the total number of **protons** and **neutrons** in the nucleus. This can vary sometimes because the number of neutrons can vary even within an element (i.e. Isotopes)

Note: The weight of **electrons**, compared to the weight of the **protons** and **neutrons**, is so small that it is not considered as being part of the above numbers!

Atoms combine to form Compounds by Chemical Bonding

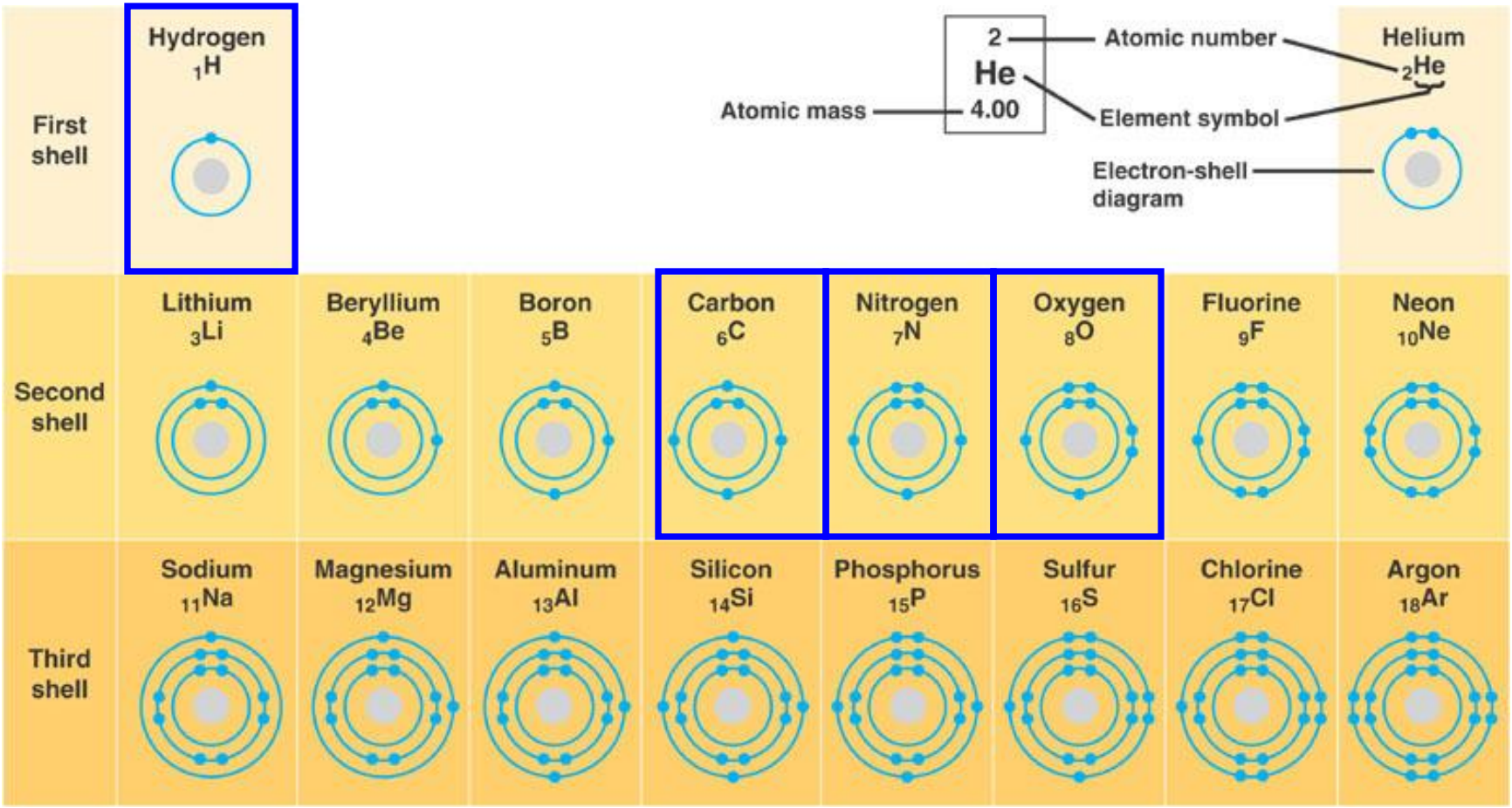
When 2 atoms approach each other, their outermost (**valence**) electrons interact. Valence electrons of one atom can interact with valence electrons of other atoms to form chemical bonds.

Atoms with all their electron shells **filled** are **inert** - chemically unreactive. (He, Ar, and Ne are examples)

Atoms with their outermost (valence) electron shell **unfilled** are highly **chemically reactive** - they will share or donate electrons with other atoms to complete their valence shell, becoming more stable, and in the process forming a **chemical bond. The "goal" = fill the valence shell = forming a chemical bond.**

All 4 of the main elements of life have unfilled valence shells and are highly chemically reactive!

Valences of Various Elements



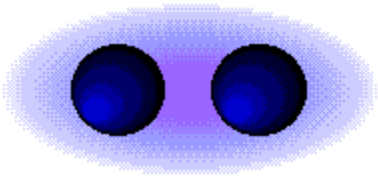
Hydrogen, Carbon, Nitrogen, Oxygen all have unfilled valences making them highly reactive.

The three main types of chemical bonds:

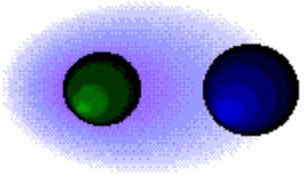
COVALENT, IONIC, HYDROGEN

1. Covalent bond: A **covalent** bond is formed if the valence electrons are shared between the 2 atoms

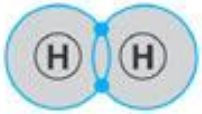
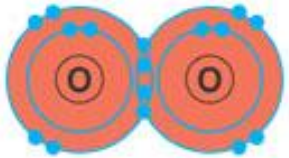
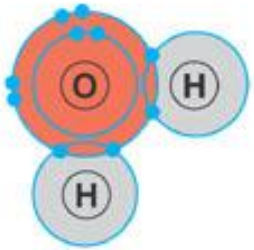
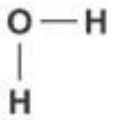
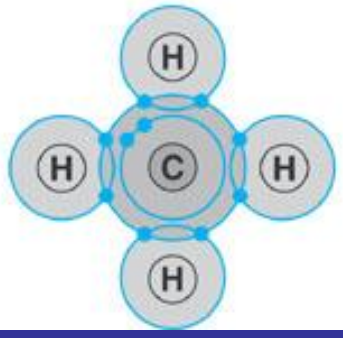
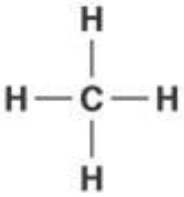
a. Nonpolar covalent bond: electrons are **shared equally**; O_2, H_2, CH_4



b. Polar covalent bond: electrons are **not shared equally**, one atom is more electronegative than another (pulls electrons more strongly); example: water - H_20.



Covalent Bond Examples

Name (molecular formula)	Electron-shell diagram	Structural formula	Space-filling model
(a) Hydrogen (H_2)			
(b) Oxygen (O_2)			
(c) Water (H_2O)			
(d) Methane (CH_4)			

Covalent bonds are very strong

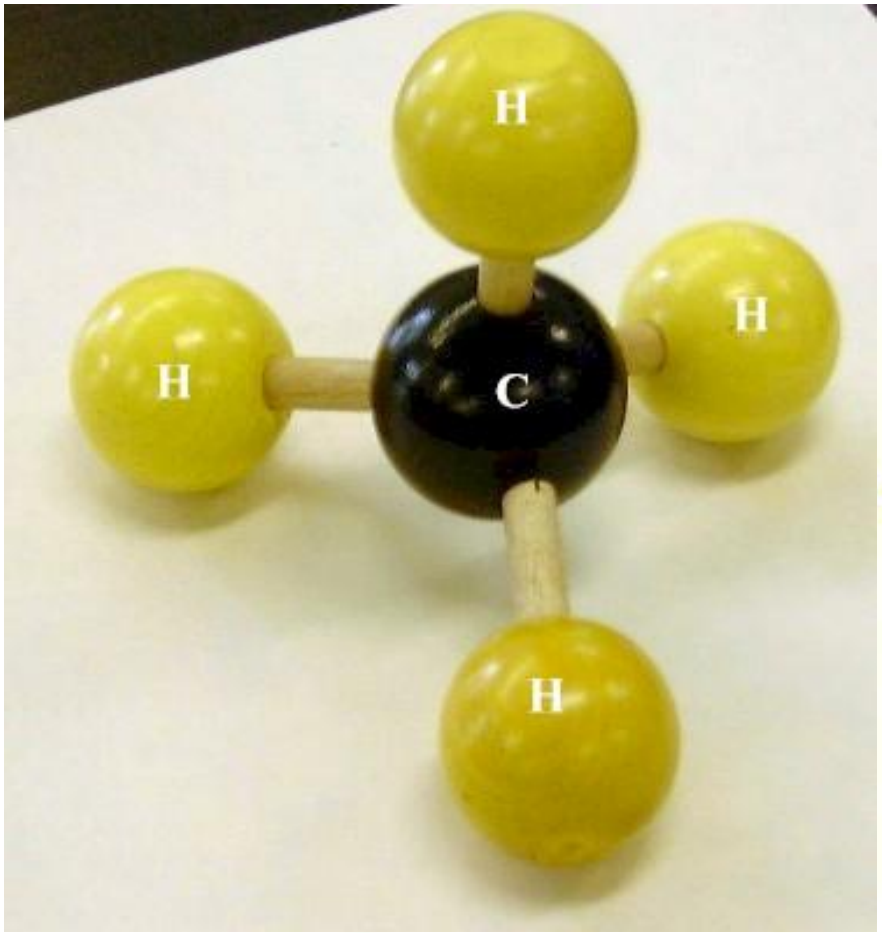
They involve a degree of electron sharing between atoms

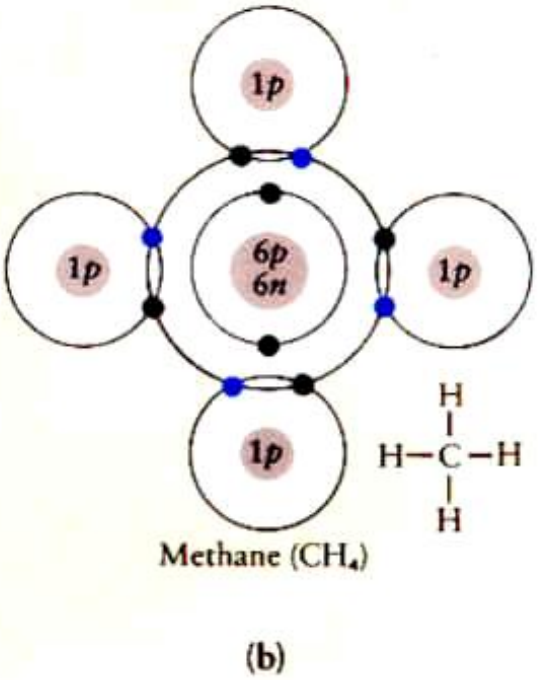
Nonpolar covalent bond

– The atoms have similar electronegativities

– Share the electron equally

Non-Polar Molecule



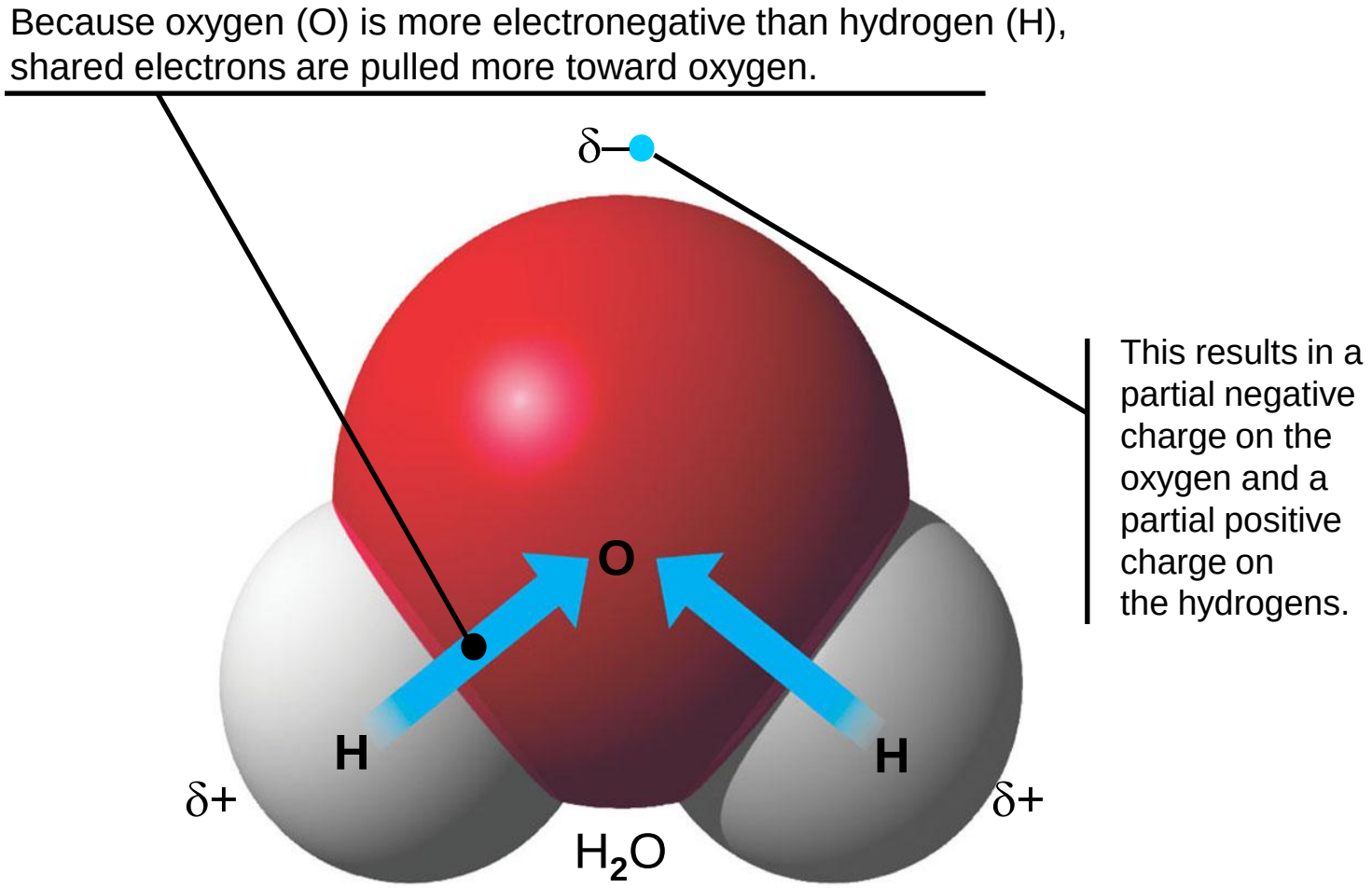


Orbital Model: Methane Molecule

Polar covalent bond

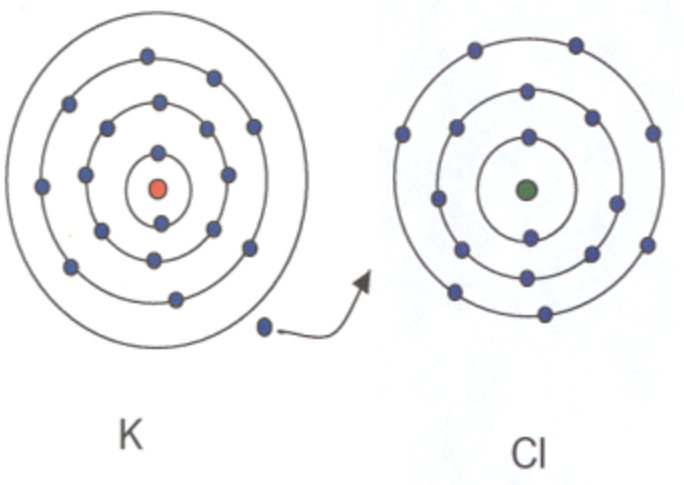
- The atoms have differing electronegativities
- Share the electrons unequally

Polar Molecule

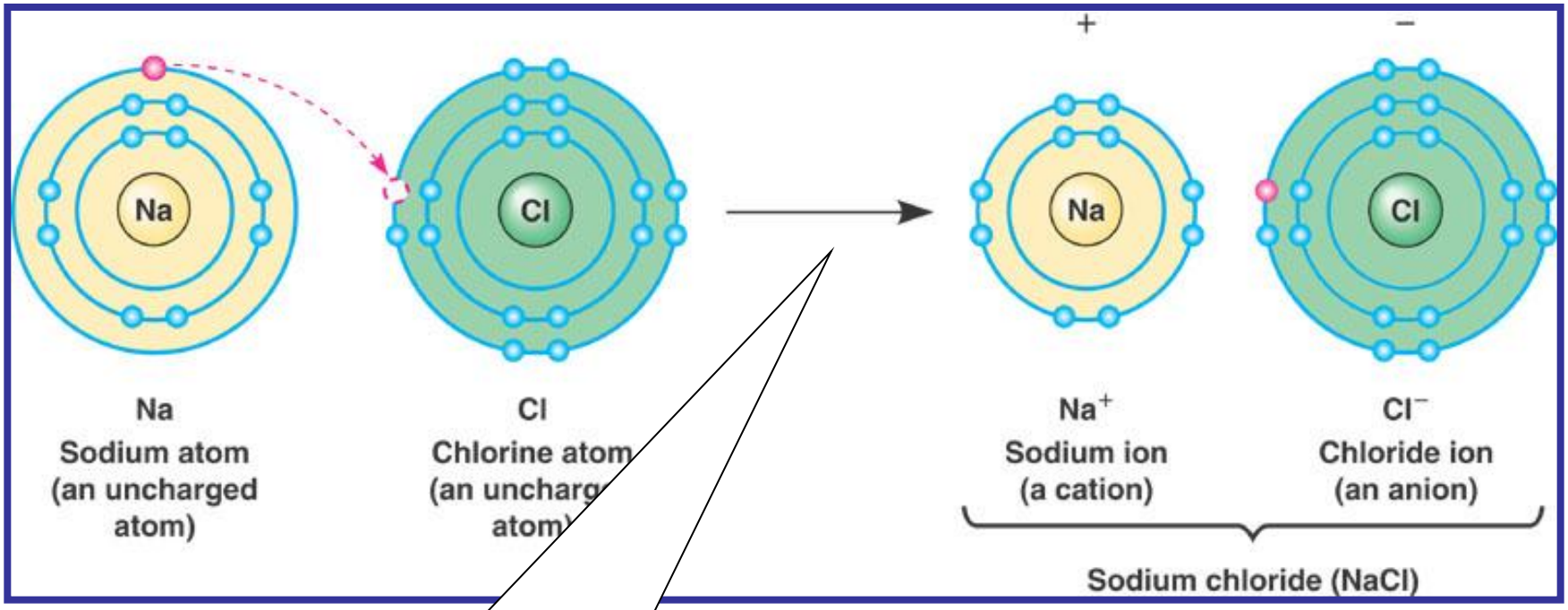


2. Ionic bond: An **ionic** bond is formed when the two atoms are so unequal that the more electronegative atom strips the electron completely away from its partner; example: NaCl

- The resulting atoms are called **ions**: Positive (**+ cations**) or negative (**- anions**)
- Ionic compounds are called **salts:** NaCl, KCl, $CaCl_2$, etc…



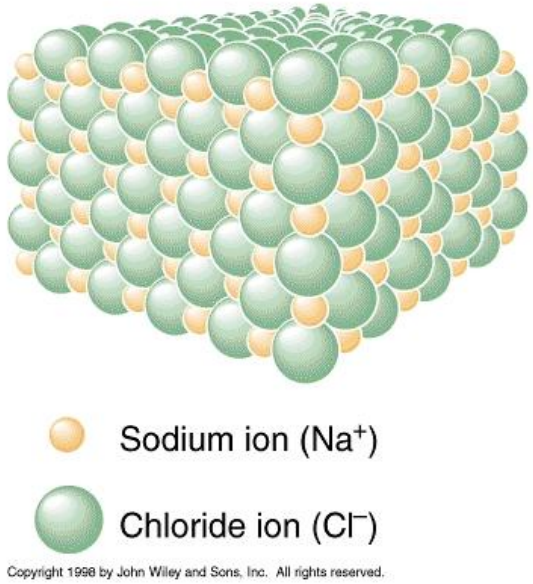
Ionic Bonding



Ionic bonds result from one atom essentially giving an electron to another atom

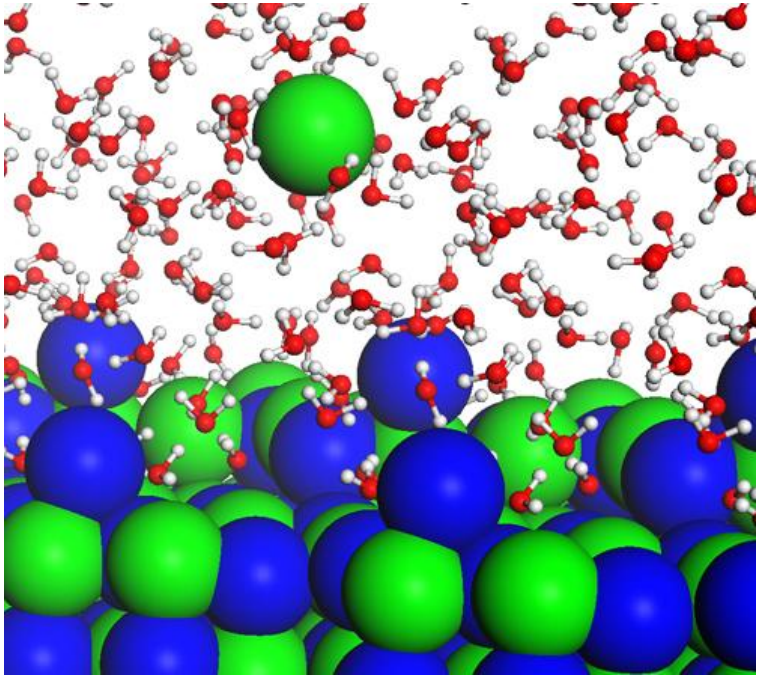
- **Ionic bonds represent an extreme of polarity and are represented in biological systems as the salt bridges within proteins**

Strong Bonds in Solid



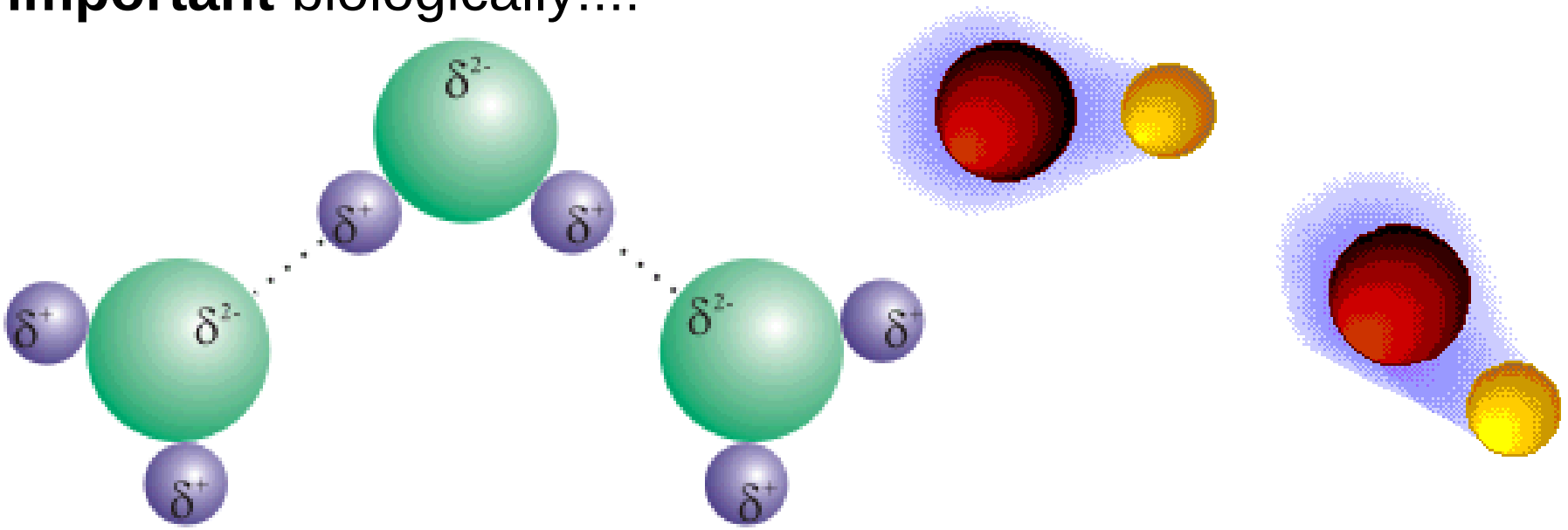
In solid phase ionic bonds can be very strong

But in aqueous phase ionic bonds tend to be weaker than covalent bonds



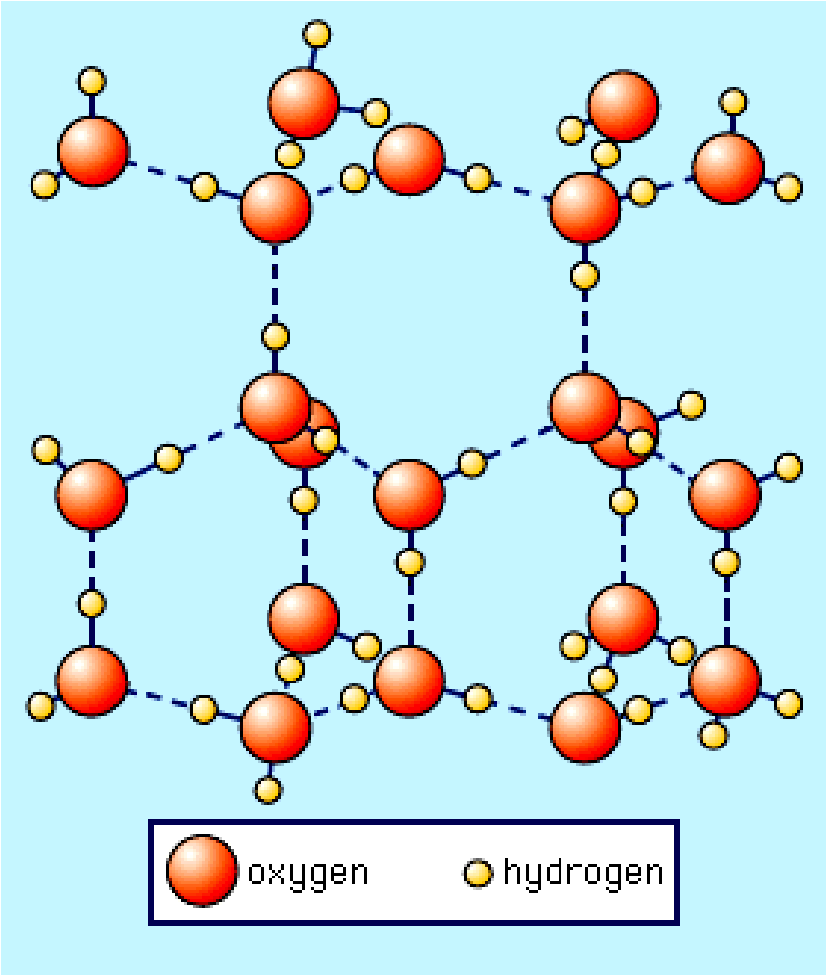
Hydrogen Bonding

3. Hydrogen bond: A weak attraction **between** one molecule and another. **Hydrogen** will bind weakly to other electronegative atoms (like oxygen, nitrogen). Unlike other bonds, hydrogen bonds are very easy to break, and form and re-form quickly (kind of like a square dance...). However, even though they are **weak** and **transient**, they are **extremely important** biologically!!!!



Hydrogen Bonds

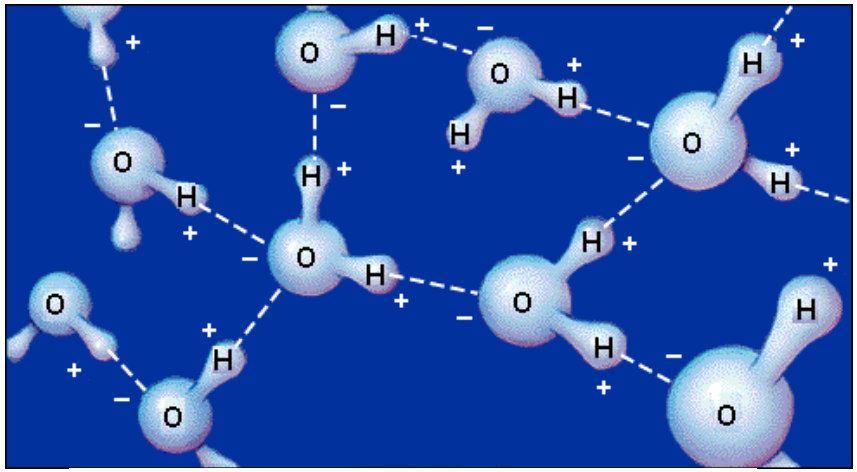
A hydrogen bond forms when a hydrogen atom covalently bonded to one electronegative atom is also attracted to another electronegative atom



Hydrogen bonding is what gives water its incredible abilities and makes life

Water and its Physical Properties

Water is known as the "universal" solvent



Water is essential for life.
It is the primary component of all living organisms

- Humans 70%
- Plants 95%
- Even the Planet is 71%

Water can store large amounts of heat

- The World's and the human body's buffer

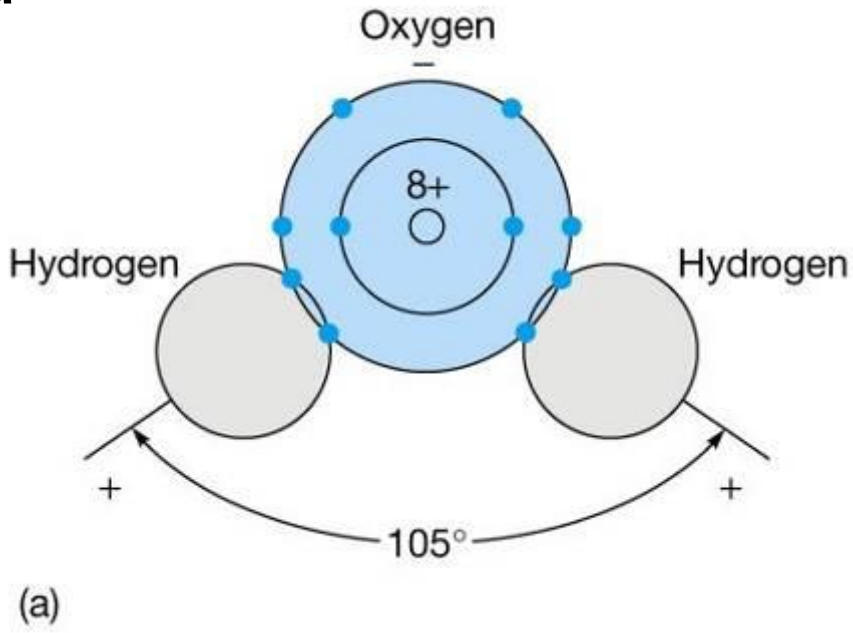
The Water Molecule

Composed of 1 oxygen and 2 hydrogen atoms (H_20)

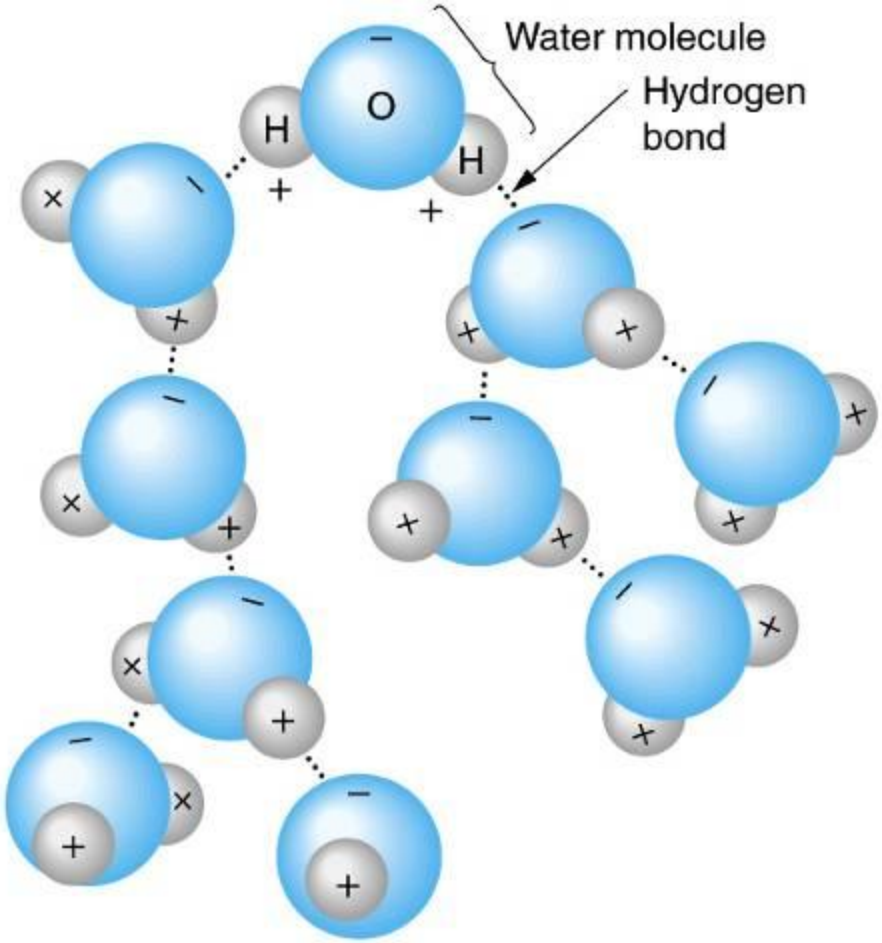
Contains strong (covalent) bonds between atoms

Unusual bend in geometry

Has polarity (oppositely charged ends)



Hydrogen Bonding



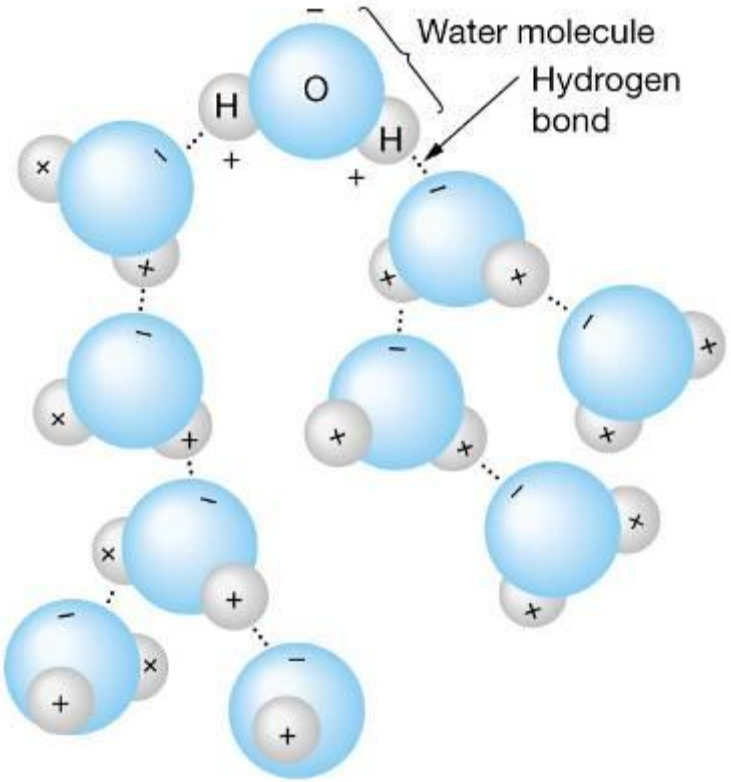
Asymmetric molecule shape causes (-) charge on O end and (+) charge on H end

Electric charges stick molecules together, called “hydrogen bonding”

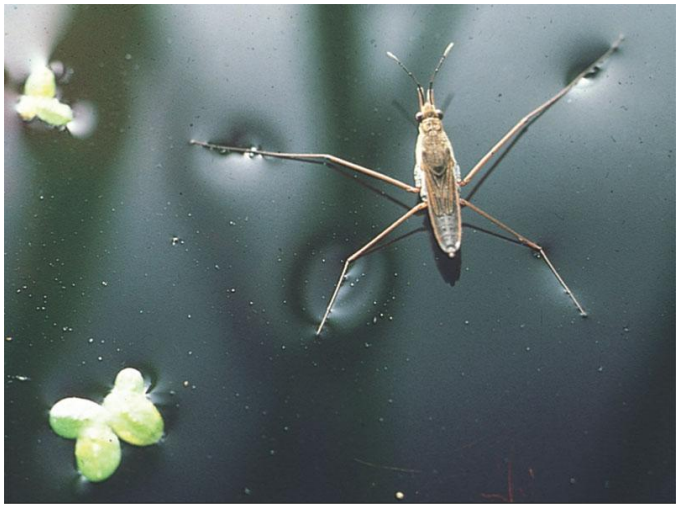
Relatively weak bonds

The Water Molecule

- Polarity causes water molecules to form weak (hydrogen) bonds between water molecules
- Water sticks to itself and to other substances
  - i.e. COHESION & ADHESION
- Allows water to be the universal solvent

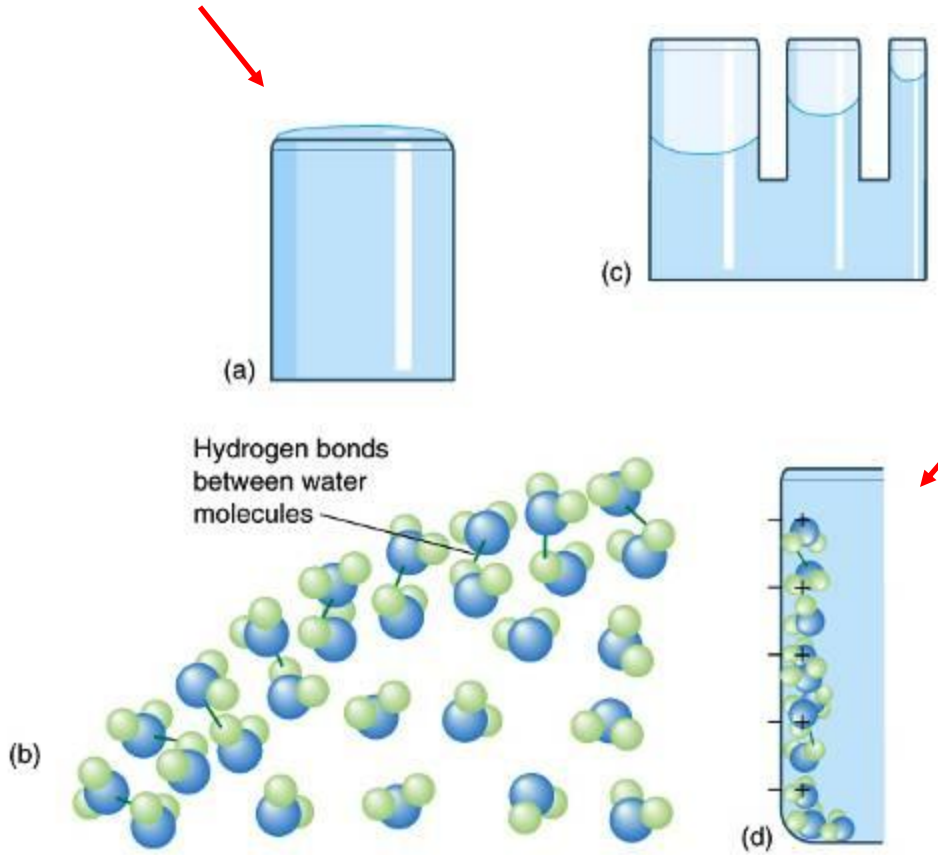


Hydrogen Bond Properties



High surface tension - Cohesion

- Bonds offset gravity in a very full glass
- Also the reason for droplet formation



Water clings to negative charged surfaces

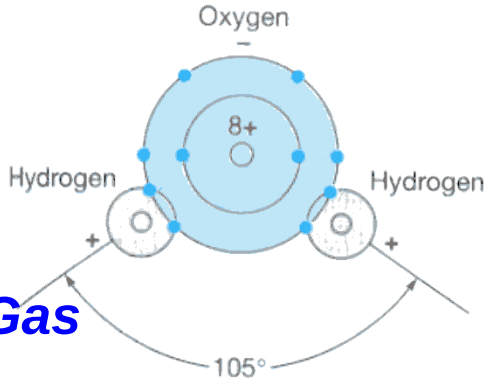
- Adhesion
- Capillarity

Thin tube can draw water up.

Its how plants get water and nutrients to its leaves

Unusual Properties of Water

Water (H_2O) is a dipolar, charged molecule
Forms hydrogen bonds
Easily dissolves compounds with ionic bonds



Water exists on Earth in 3 states: Solid, Liquid, and Gas

Important Thermal Properties

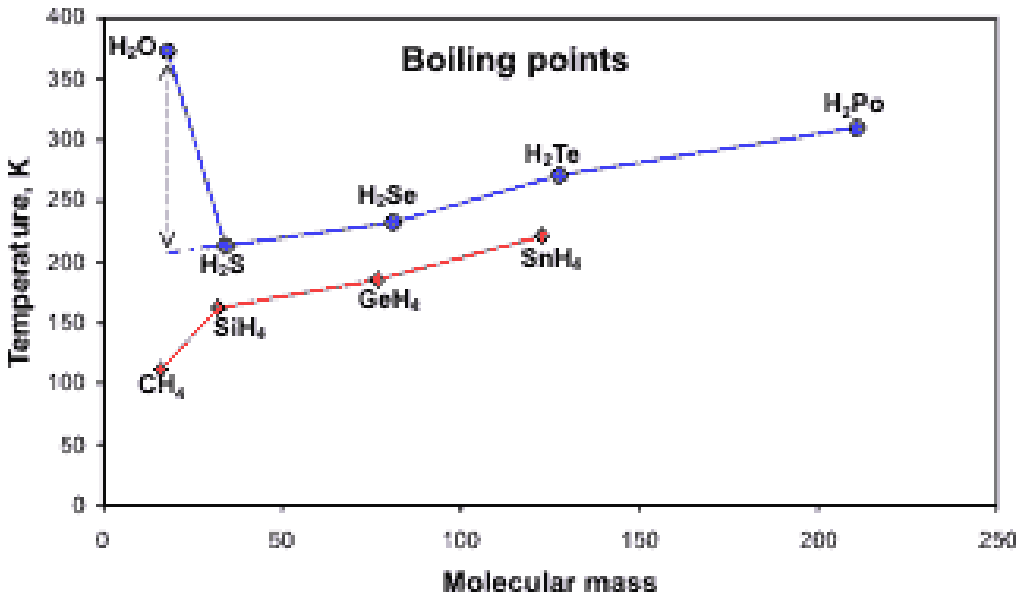
High **freezing and boiling points because of H-bonding and van der Waals' forces**
High **heat capacity - gains/loses more heat than other substances**
High **latent heat of vaporization (evaporation)**
High **latent heat of melting**

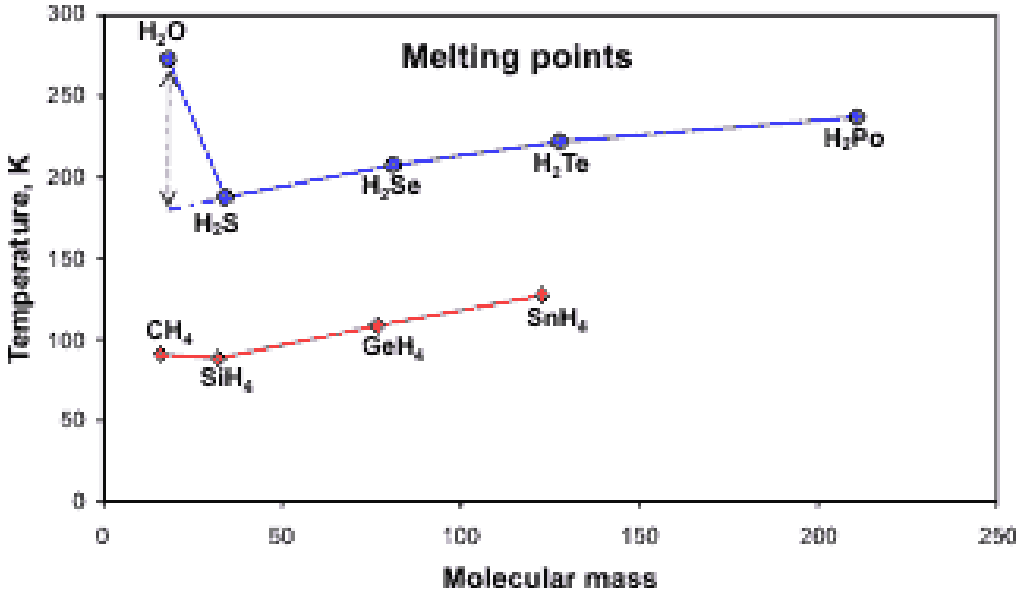
Calorie - amount of heat required to raise the temperature of one gram of water by 1°C

Boiling & Melting Points

- **Water has a relatively high boiling temperature**
- **Water has a relatively high melting point**

The additional energy is required to over come the forces that hold it together

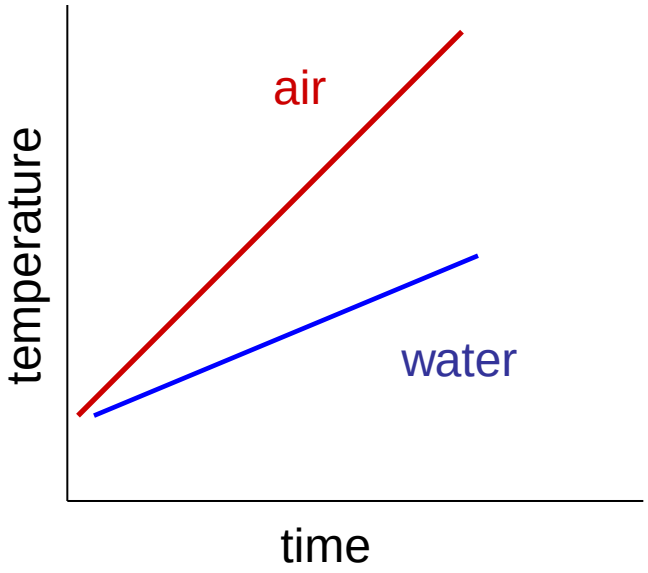




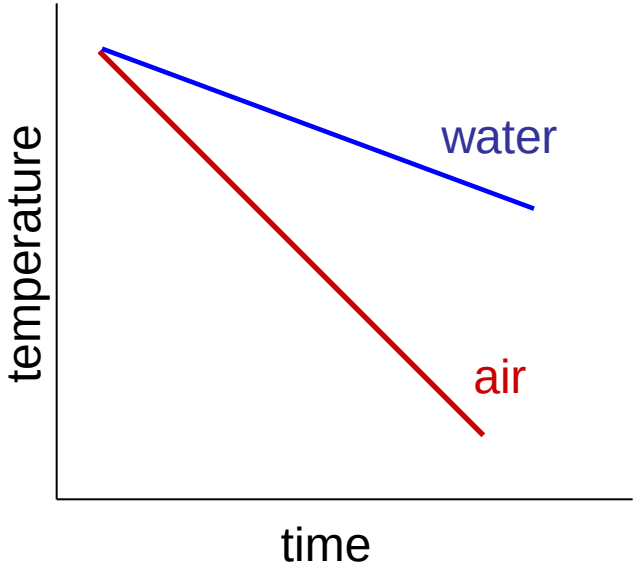
Heat Capacity

Water increases and decreases temperature much slower than other materials. Important for internal constancy.

Adding heat



Losing heat

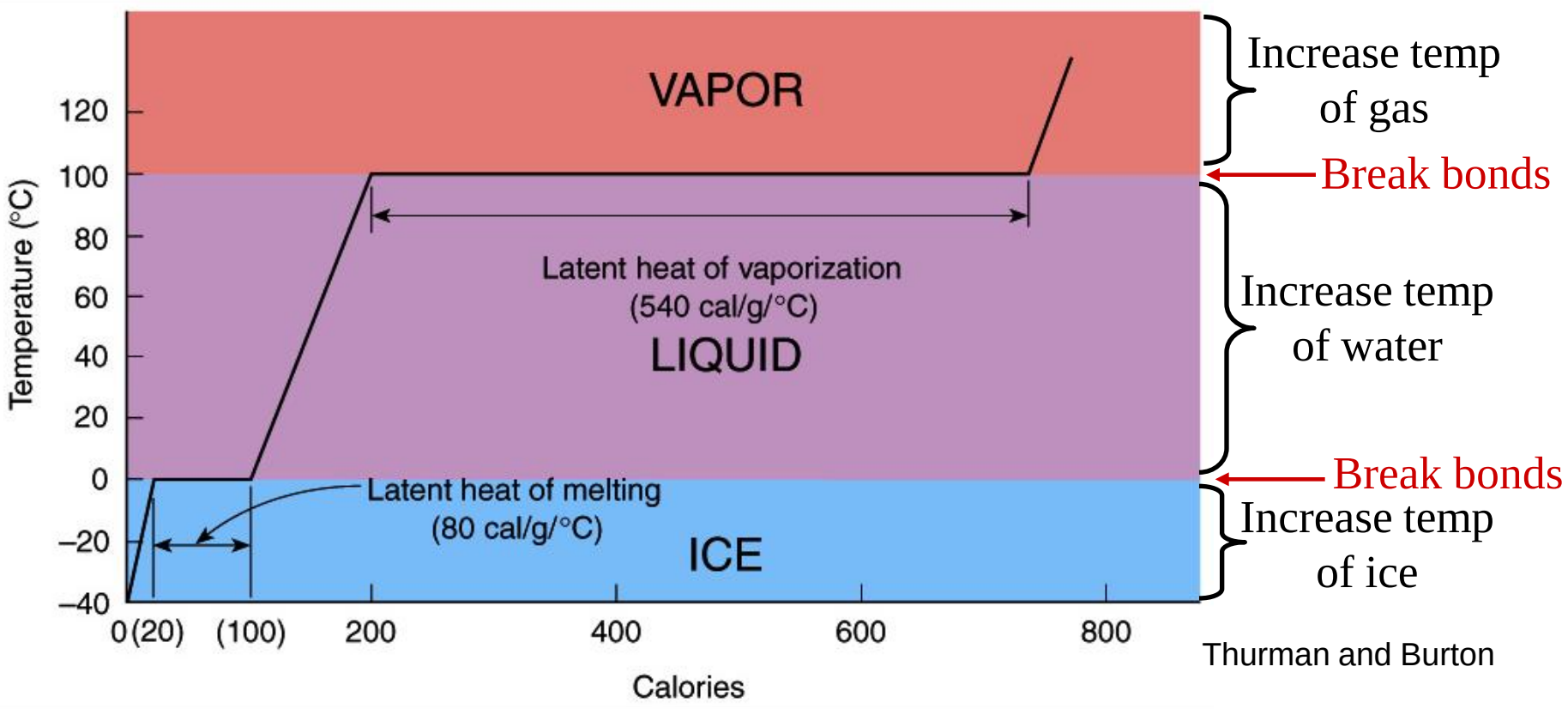


Water has a **high specific heat** - because the hydrogen bonds absorb heat. This protects organisms (made of water) from rapid temperature changes, and causes a swimming pool to stay cold even when it's hot outside!

Latent Heat and Heat Capacity

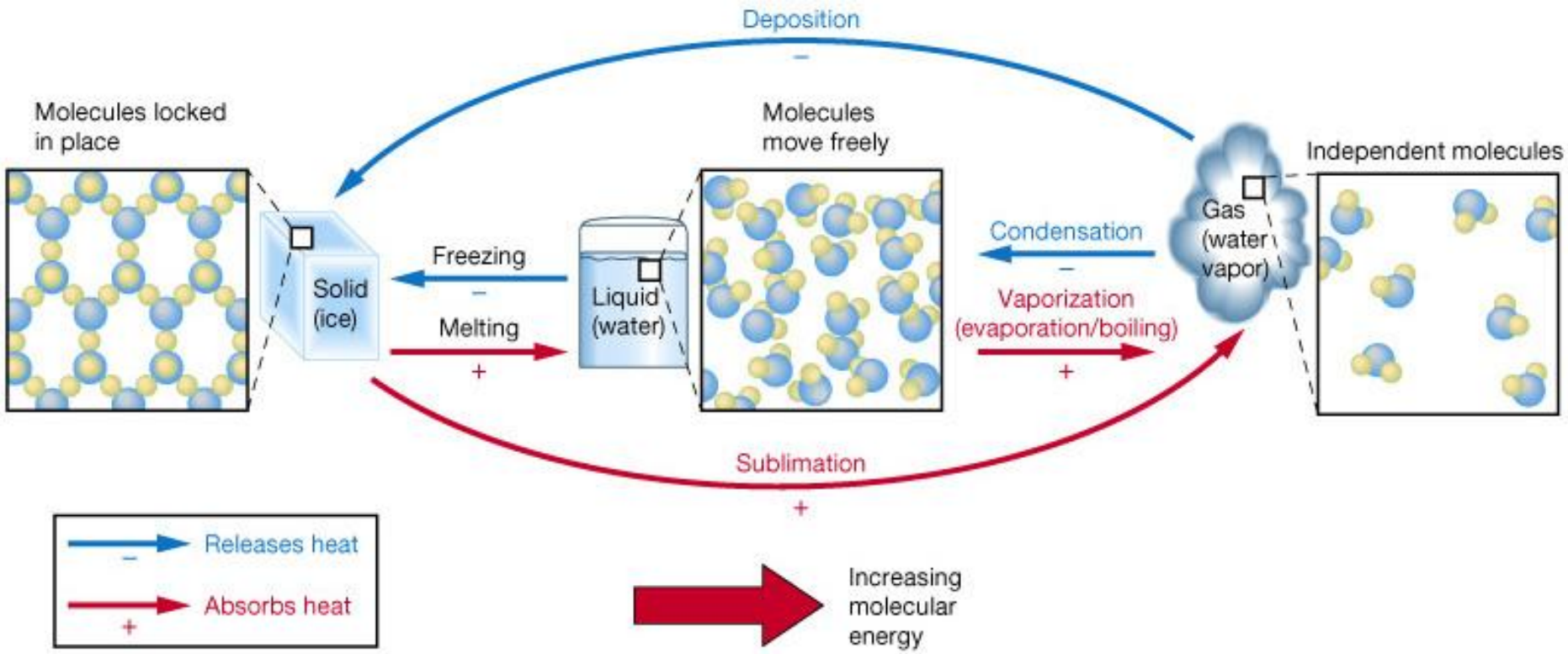
How does water move from one phase to another?

Need additional Latent heat to convert from one phase to another (i.e to break molecular bonds)



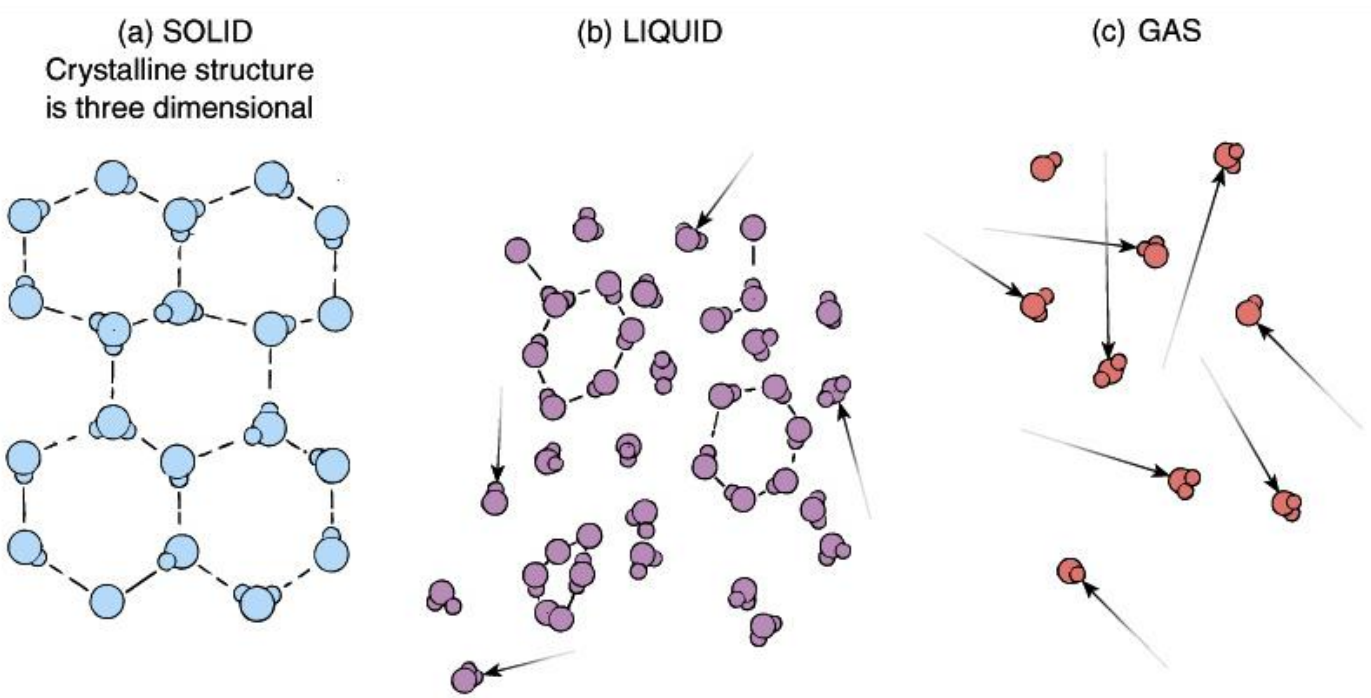
Latent Heat Capacity

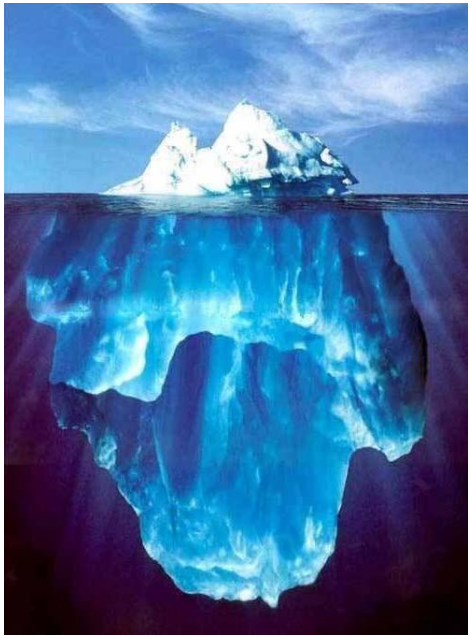
Latent (hidden) heat = energy that is either absorbed or released as water changes state



Water expands upon freezing (ice floats!)

As water cools to freezing, water molecules stop moving; hydrogen bonds lock water molecules in a crystal 10% **less dense** than liquid water. Floating ice insulates the water, allowing life to continue underneath.





Water molecules stick together with hydrogen bonds

At freezing Temp. they form rigid lattice- ICE

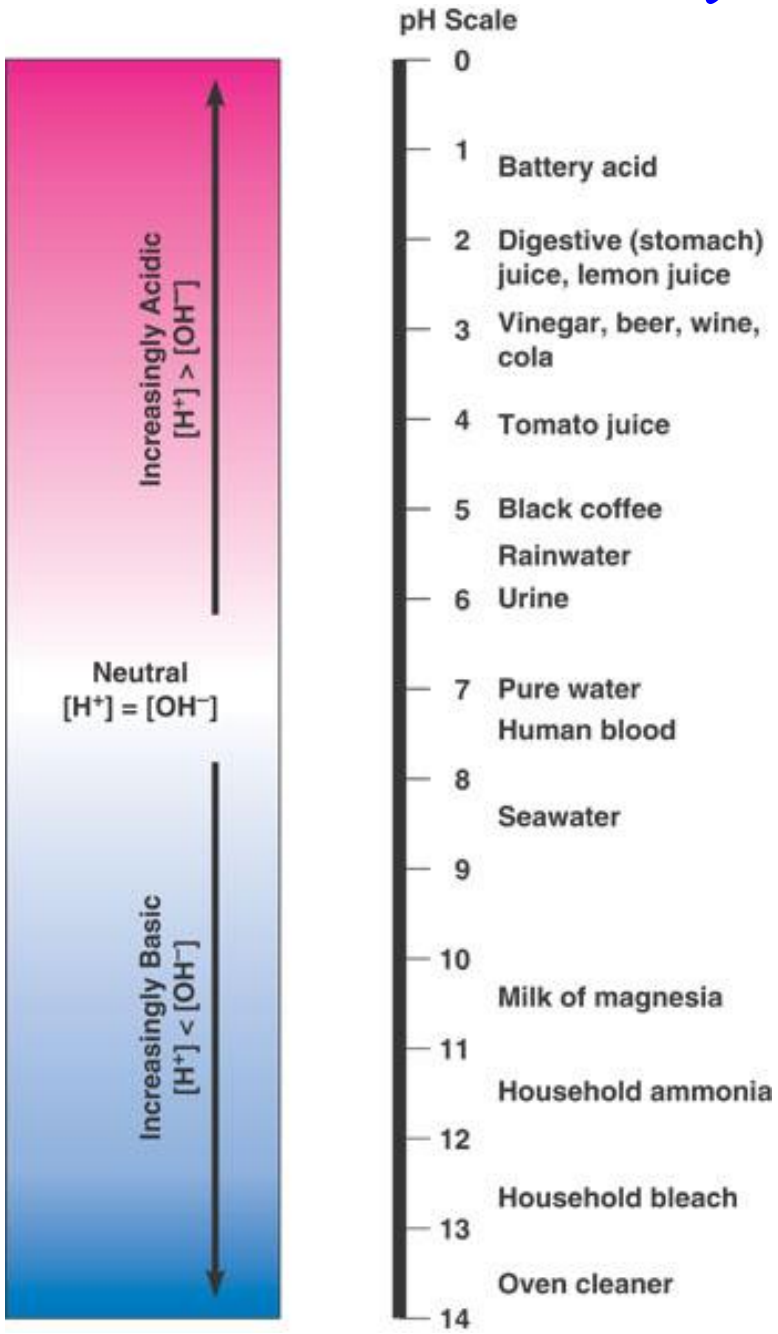
At medium temp (0-100), only some are still stuck together in clumps (water)

At high temp, all molecules are separate (gas)

Water occasionally ionizes (splits into H^+ and OH^-)

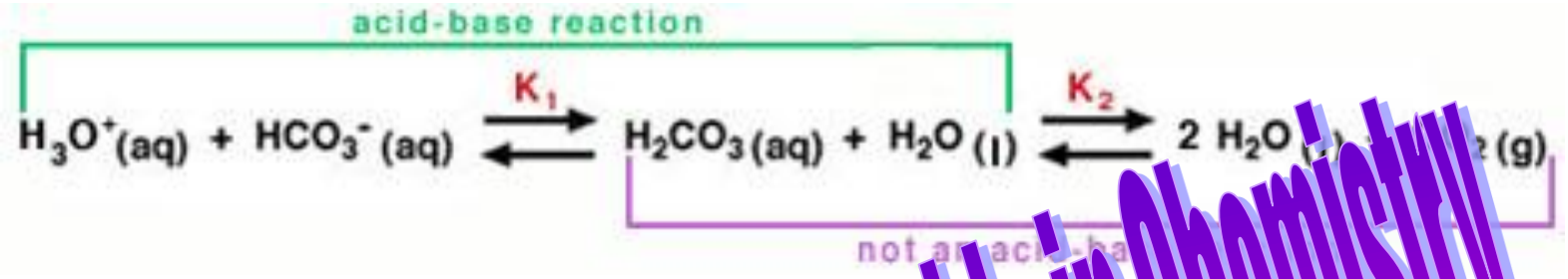
- The pH scale ("percent Hydrogen") measures the concentration of H^+ is in a solution, and runs from 0-14. Each number represents a **10-fold** difference in $[H^+]$
- In pure water, H+ and OH- are equal (neutral) $[H^+] = [OH^-]$, pH is 7 = neutral
- Addition of an acid **lowers** the pH (increases the $[H^+]$), pH below 7 = acidic
- Addition of a base **increases** the pH (decreases the $[H^+]$), pH above 7 = basic
- Internal pH of cells = ~7.4. Chemical reactions are very sensitive to pH; we cannot live for more than a few minutes at pH 7.0 or 7.8!

- **Buffers** (example: sodium bicarbonate in our bloodstream) allow solutions (like cytoplasm) to **resist** changes in pH by **soaking up excess** H^+ or **donating** H^+ when scarce.



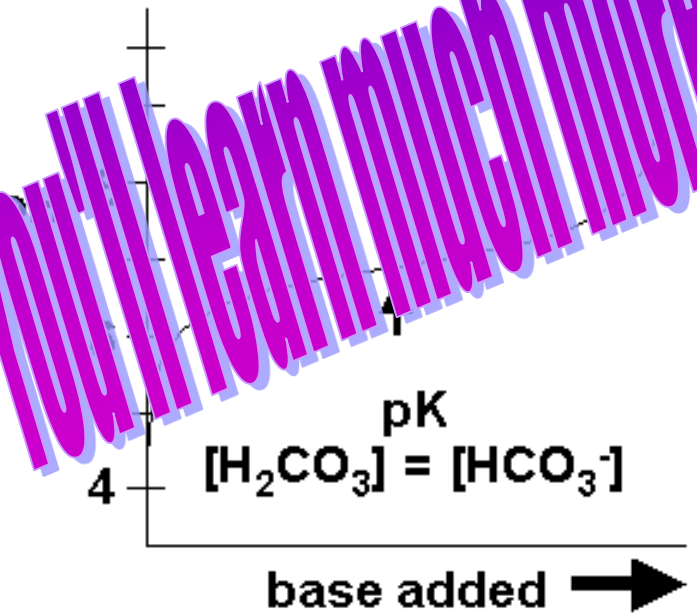
Carbonic-Acid-Bicarbonate Buffering (e.g. blood)

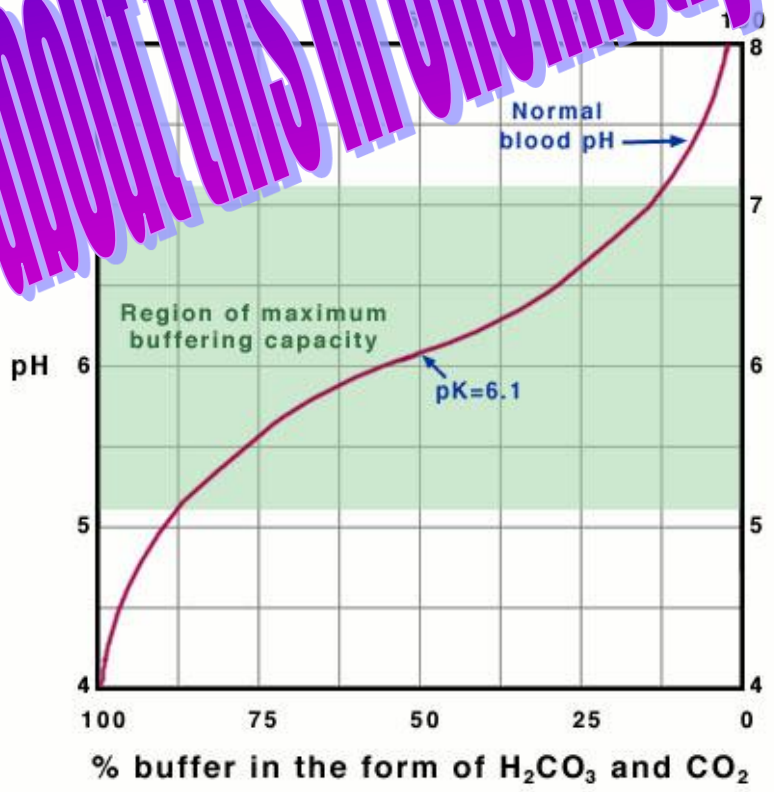
pH Buffering



>pH = less $H_3O^+ \approx H^+$

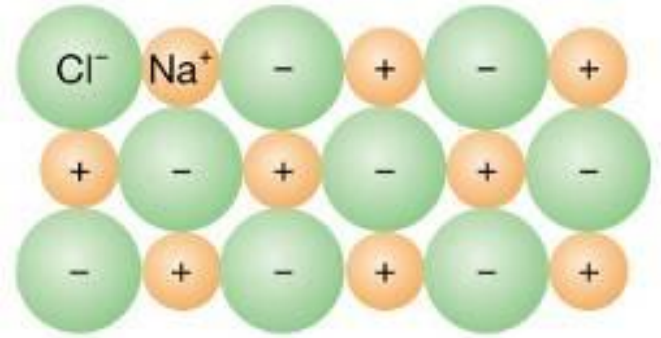
You'll learn much more about this in Chemistry



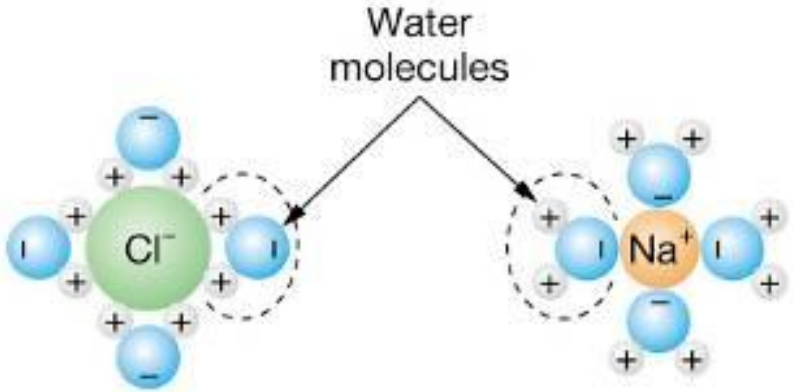


The Water Molecule
Solvent Power

- Water molecules can stick to other compounds
- They reduce the attraction of ionic bonds in other substances and split them up
  - **i.e. they DISSOLVE them**
- Readily dissolves **hydrophilic** chemicals like sugar, salt (**solutes**)
- Water **repels** uncharged **hydrophobic** molecules like oil, cell membranes, or wax, excluding them from solution

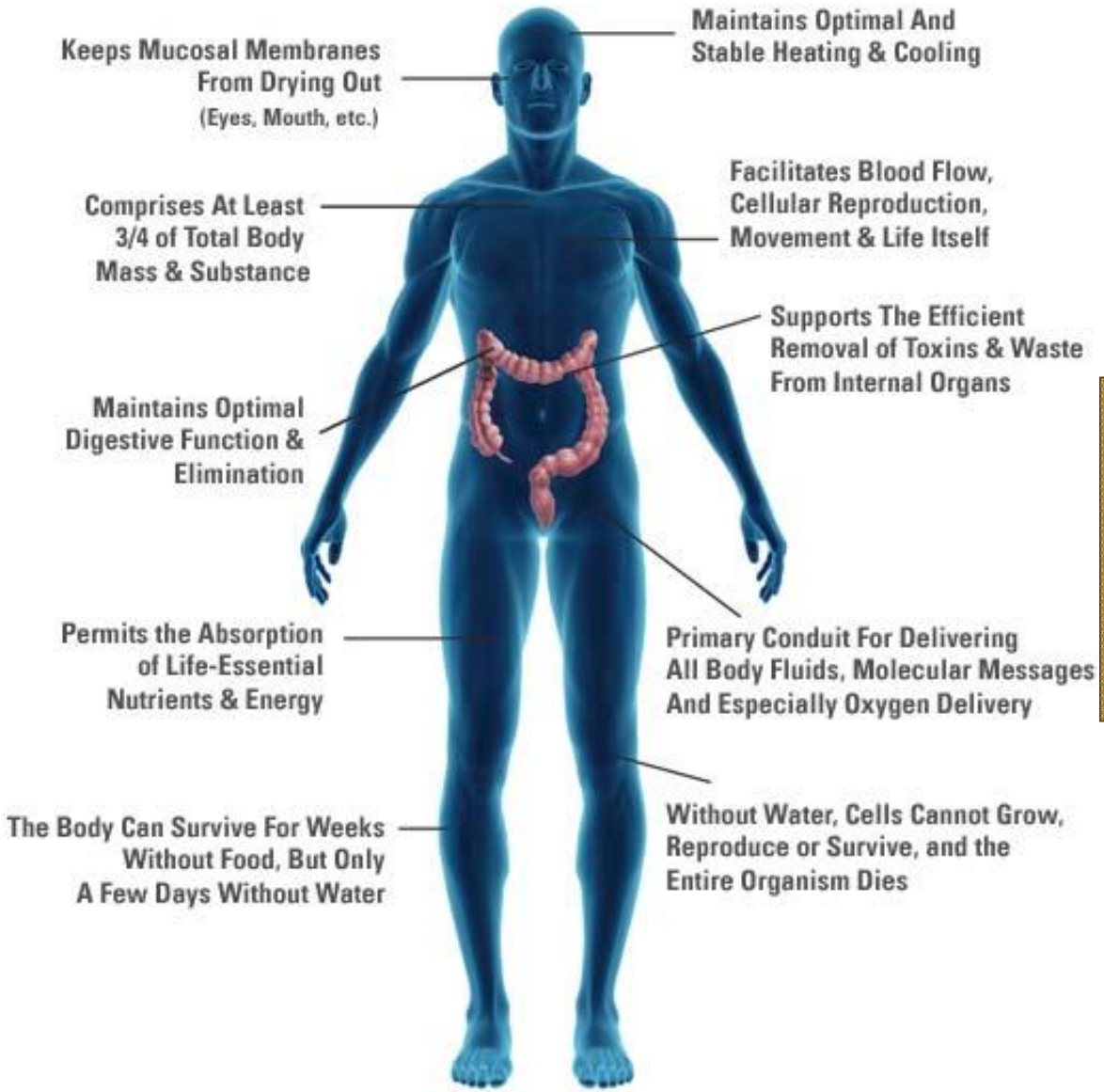


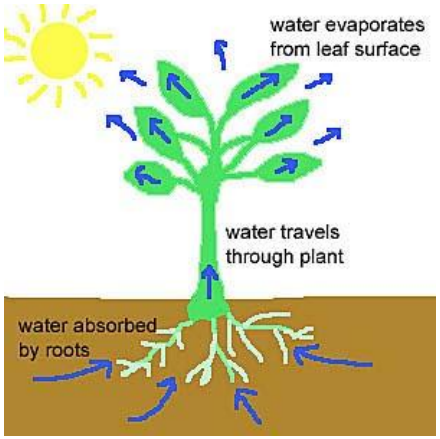
(a) Sodium chloride, solid crystal structure

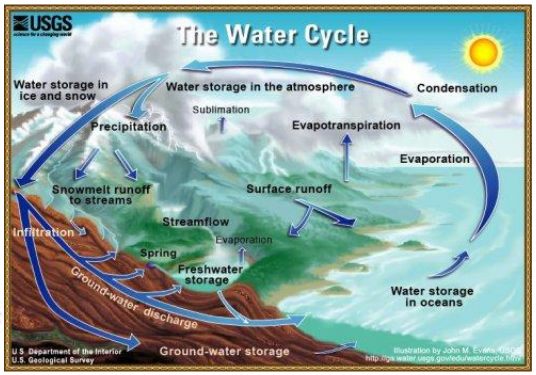


(b) Sodium chloride, in solution

Water- Crucial for Life







The most important property of water to the existence of life has to do with the ability of water to dissolve some substances and exclude others

Water- Crucial for Cell Life

Uses as reactant	Takes part in many metabolic reactions. e.g. hydrolysis of sugar, raw material for photosynthesis.
Uses as solvent	Good solvent for inorganic and many small organic substances.
Acts as medium for transportation	Liquid nature, can flow from one area to others. many chemicals can dissolve in it.
Acts as medium for chemical reaction	Many chemicals can dissolve in it. Not easily subjected to large temperature fluctuation, thus reactions can take place at a constant rate.
Provides support	provides turgidity to support herbaceous plants and small organisms. Provides buoyancy for aquatic organisms
Others	decreases body temperature by evaporation of water from body surface e.g. sweat Necessary for forming body secretion e.g. digestive juice medium for fertilization of eggs and sperms in mammals