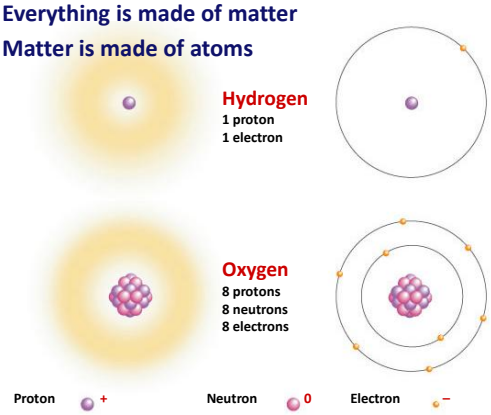
Chemistry of Life

- Everything is made of matter
- Matter is made of atoms

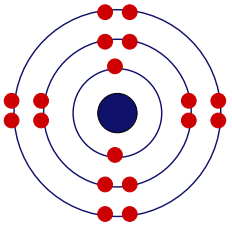


Life requires ~25 chemical elements

- About 25 elements are essential for life
  - Four elements make up 96% of living matter:
    - carbon (C)
    - hydrogen (H)
    - oxygen (O)
    - nitrogen (N)
  - Four elements make up most of remaining 4%:
    - phosphorus (P)
    - calcium (Ca)
    - sulfur (S)
    - potassium (K)

Bonding properties

- Effect of electrons
  - electrons determine chemical behavior of atom
  - depends on number of electrons in atom's outermost shell
    - valence shell

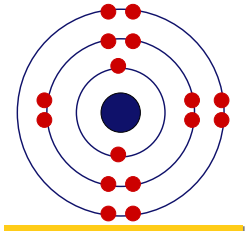


How does this atom behave?

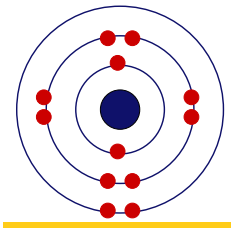
Bonding properties

What's the magic number?

- Effect of electrons
  - chemical behavior of an atom depends on number of electrons in its valence shell

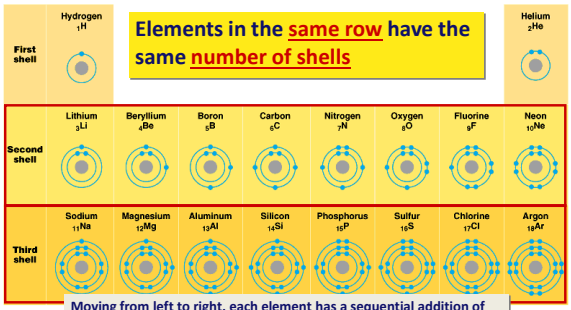


How does this atom behave?



How does this atom behave?

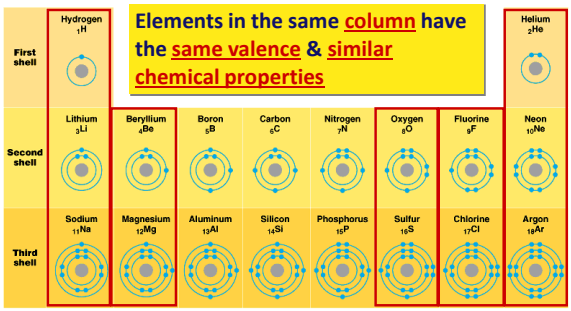
Elements & their valence shells



Elements in the same row have the same number of shells

Moving from left to right, each element has a sequential addition of electrons (& protons)

Elements & their valence shells



Elements in the same column have the same valence & similar chemical properties

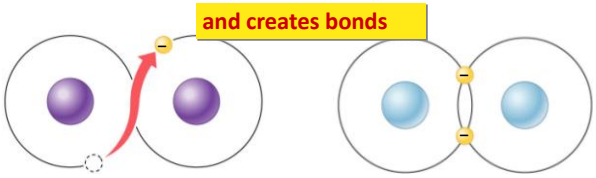
Chemical reactivity

- Atoms tend to
  - complete a partially filled valence shell

    or
  - empty a partially filled valence shell

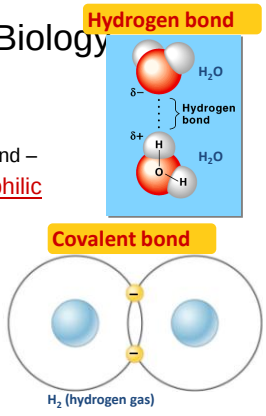
This tendency drives chemical reactions…

and creates bonds



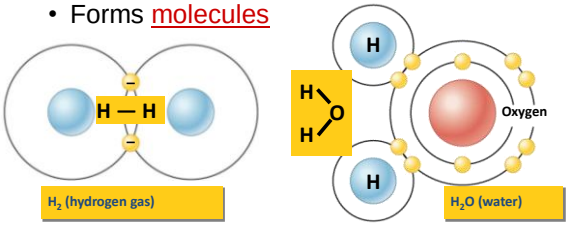
Bonds in Biology

- Weak bonds
  - hydrogen bonds
    - attraction between + and –
  - hydrophobic & hydrophilic interactions
    - interaction with H_2O
  - van derWaals forces
  - (ionic)
- Strong bonds
  - covalent bonds



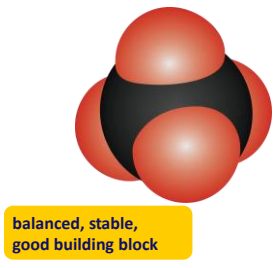
Covalent bonds

- Why are covalent bonds strong bonds?
  - two atoms share a pair of electrons
  - both atoms holding onto the electrons
  - very stable
- Forms molecules



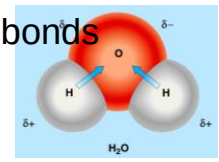
Nonpolar covalent bond

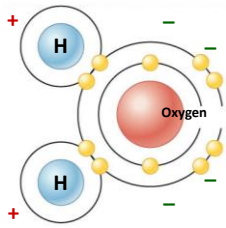
- Pair of electrons shared equally by 2 atoms
  - example: hydrocarbons = C_xH_x
    - methane (CH_4)



Polar covalent bonds

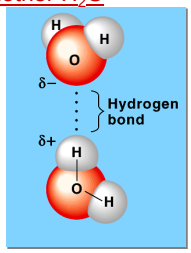
- Pair of electrons shared unequally by 2 atoms
  - example: water = H_2O
    - oxygen has stronger "attraction" for the electrons than hydrogen
    - oxygen has higher electronegativity
    - water is a polar molecule
      - + vs – poles
      - leads to many interesting properties of water…



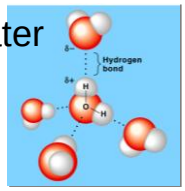


Hydrogen bonding

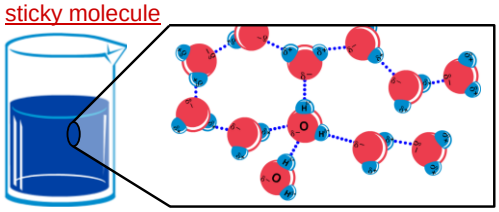
- Polar water creates molecular attractions
  - attraction between positive H in one H_2O molecule to negative O in another H_2O
  - also can occur wherever an -OH exists in a larger molecule
- Weak bond



Chemistry of water



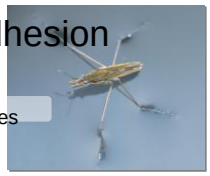
- H_2O molecules form H-bonds with each other
  - +H attracted to –O
  - creates a sticky molecule



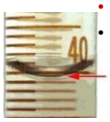
Elixir of Life

- Special properties of water
  1. cohesion & adhesion
     - surface tension, capillary action
  2. good solvent
     - many molecules dissolve in H_2O
     - hydrophilic vs. hydrophobic
  3. lower density as a solid
     - ice floats!
  4. high specific heat
     - water stores heat
  5. high heat of vaporization
     - heats & cools slowly

1. Cohesion & Adhesion

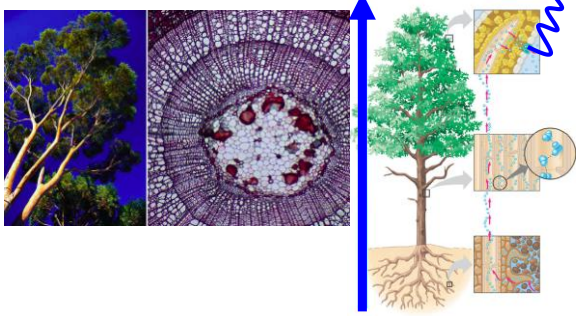


- Cohesion
  - H bonding between H_2O molecules
  - water is "sticky"
    - surface tension
    - drinking straw
- Adhesion
  - H bonding between H_2O & other substances
    - capillary action
    - meniscus
    - water climbs up paper towel or cloth



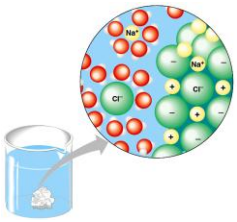
How does H_2O get to top of trees?

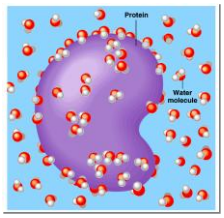
Transpiration is built on cohesion & adhesion



2. Water is the solvent of life

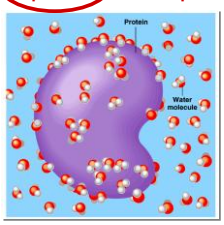
- Polarity makes H_2O a good solvent
  - polar H_2O molecules surround + & – ions
  - solvents dissolve solutes creating solutions

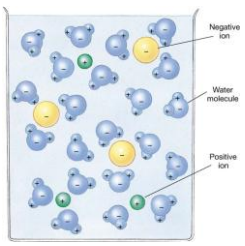




What dissolves in water?

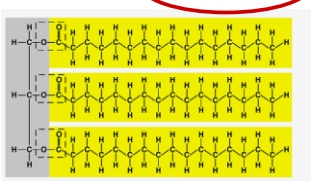
- Hydrophilic
  - substances have attraction to H_2O
  - polar or non-polar?





What doesn't dissolve in water?

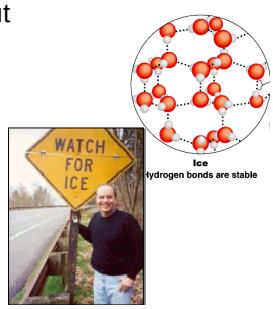
- Hydrophobic
  - substances that don't have an attraction to H_2O
  - polar or non-polar?



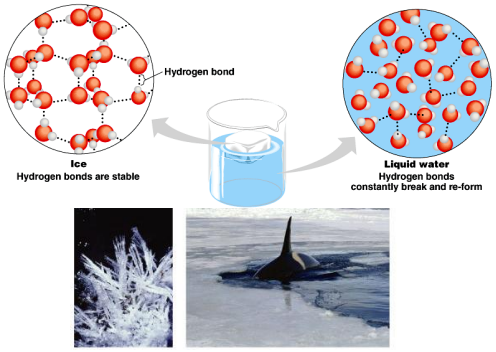
fat (triglycerol)

3. The special case of ice

- Most (all?) substances are more dense when they are solid, but not water…
- Ice floats!
  - H bonds form a crystal

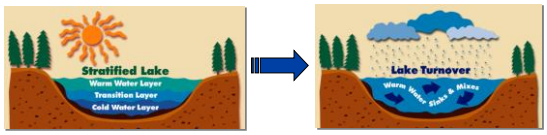


Ice floats



Why is "ice floats" important?

- Oceans & lakes don't freeze solid
  - surface ice insulates water below
    - allowing life to survive the winter
  - if ice sank…
    - ponds, lakes & even oceans would freeze solid
    - in summer, only upper few inches would thaw
  - seasonal turnover of lakes
    - sinking cold H_2O cycles nutrients in autumn

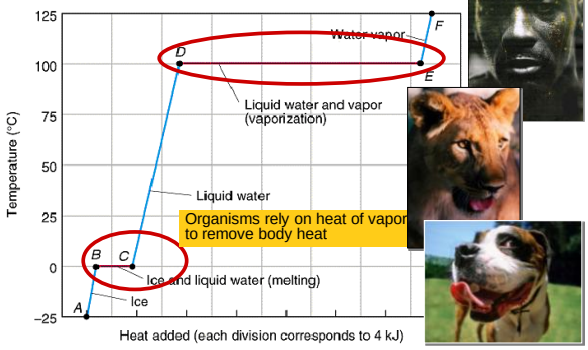


4. Specific heat

- H_2O resists changes in temperature
  - high specific heat
  - takes a lot to heat it up
  - takes a lot to cool it down
- H_2O moderates temperatures on Earth

5. Heat of vaporization

Evaporative cooling



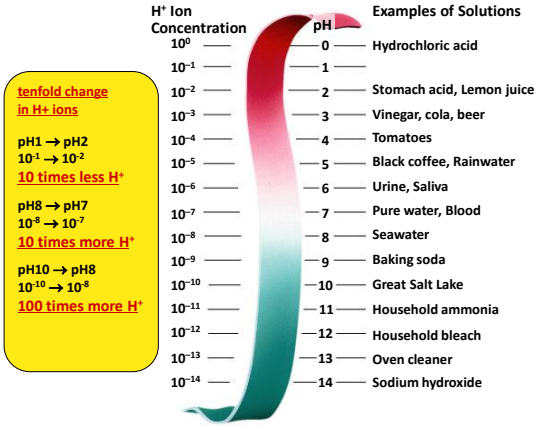
Ionization of water & pH

- Water ionizes
  - H^+ splits off from H_2O, leaving OH^-
    - if $[H^+] = [^-OH]$, water is neutral
    - if $[H^+] > [^-OH]$, water is acidic
    - if $[H^+] < [^-OH]$, water is basic
- pH scale
  - how acid or basic solution is
  - $1 \rightarrow 7 \rightarrow 14$

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

Ionization of water & pH

- pH = -log[H+]
  - Higher [H+] = lower pH
- $[H+][OH-] = 10^{-14}$
  - $n^a n^b = n^{a+b}$



Buffers & cellular regulation

- pH of cells must be kept ~7
  - pH affects shape of molecules
  - shape of molecules affect function
  - pH affects cellular function
- Control pH by buffers
  - reservoir of H^+
    - donate H+ when $[H^+]$ falls
    - absorb H+ when $[H^+]$ rises