A review of bonds
Abundance and importance of water
What’s so special about water
Water and solutions

Why should we study water itself?
Living things are made of 70-90% water.
Water is essential for all life on Earth (possibly all life).

Review: What is matter?
Anything that:
- Takes up space
- Has mass

So this includes living AND non-living things.

What is matter made of?
Living and non-living matter:
- Both are made of elements

Elements cannot be broken down to substances with different properties.
So an element can’t be broken down? NO! I didn’t say that!
- Elements can be broken down to atoms, but each of the atoms will have the same properties! (i.e. the same number of protons)
- 92 natural elements (additional man-made elements are on the periodic table).

Elements
- Examples of elements include: Oxygen, Carbon, Hydrogen, Gold, Silver, Potassium, Magnesium, Lead, Helium, Lithium
- The most common elements found in living organisms: Carbon, Oxygen, Nitrogen, Hydrogen, Phosphorus, Sulfur

Periodic Table of the Elements (excerpt)
What are elements made of?

- An element consists of atoms of the same kind. (i.e. The same number of protons, or atomic number.)

- For example, every atom that has 6 protons is the element CARBON.
- Every atom that has 7 protons is NITROGEN.
- Every atom that has 8 protons is OXYGEN. Etc.

Atomic structure

- Atoms are made of sub-atomic particles:

<table>
<thead>
<tr>
<th>Particle</th>
<th>Charge</th>
<th>Location in the atom</th>
<th>Atomic mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>+1</td>
<td>Nucleus</td>
<td>1</td>
</tr>
<tr>
<td>Neutron</td>
<td>0</td>
<td>Nucleus</td>
<td>1</td>
</tr>
<tr>
<td>Electron</td>
<td>-1</td>
<td>Electron shells</td>
<td>0</td>
</tr>
</tbody>
</table>

The Periodic Table of atoms

- All atoms of the same element have the same ATOMIC NUMBER (aka, number of protons).
- Does it make more sense now?
- Any questions?
All Orbits are Full in Certain Elements

Atoms with full orbits do not have relationships with other atoms

Atoms combine to form compounds.

- When atoms of 2 (or more) elements form bonds together, the new combination is called a COMPOUND.
- Briefly review 4 types of bonding:
  1. Ionic bonds
  2. Covalent bonds (polar & nonpolar)
  3. Metallic bonds
  4. Hydrogen bonds

Sharing Electrons and Making Molecules

H₂ a gas molecule

Molecules can be made by sharing more than one electron

Needs to be full

O₂ a gas molecule

Ionic Bonds

- Ion = a charged atom (can be + or -)
- Ionic bonds are fairly weak, and are formed by the attraction between a positively charged atom and a negatively charged atom.
- Example: NaCl, p.24

Ionic Bonds

sodium atom (Na) + chlorine atom (Cl)

sodium ion (Na⁺) + chloride ion (Cl⁻)

sodium chloride (NaCl)
Covalent Bonds

- Covalent bonds are strong.
- 2 atoms literally share an electron
  - Nonpolar: both atoms share equally
  - Polar: one atom has a stronger pull on the electron
- Examples: (page 25) O₂, H₂, CH₄
- Compare the covalent bond diagrams on p25 with the ionic bond diagrams on p24.

iClicker Question

- Giving away or accepting one or more electrons in valence state, is indicative of what type of bond?
  A Covalent bond.
  B Metallic bond.
  C Ionic bond.

iClicker Question

- Sharing an electron with many other atoms without respect to an orbit is indicative of what type of bond?
  A Covalent bond.
  B Metallic bond.
  C Ionic bond.

Hydrogen Bonding

- The polarity in a water molecule causes the HYDROGEN atoms of one water molecule to be attracted to the OXYGEN atoms of another water molecule.
- Very weak bonds, but there are so many! So, as a collective force, they can be quite strong.
Structure of Water; Hydrogen Bonding

<table>
<thead>
<tr>
<th>Electron Model</th>
<th>Ball-and-stick Model</th>
<th>Space-filling Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen attracts the shared electrons and is partially negative.</td>
<td>H₂O bond</td>
<td>Hydrogen atoms are partially positive.</td>
</tr>
</tbody>
</table>

Elements of the Solar System: Role in Living Systems

- 25 of 92 natural elements essential to life on Earth
- Four of the above make up 96%
  - Carbon (C), Oxygen (O), Hydrogen (H) and Nitrogen (N)
- Solar abundance and importance relative to origin/evolution of life

Abundance of the Elements of the Periodic Table in the Solar System

Log Plot of Abundance

A Linear View of Abundance

Summary of atomic bonds

- Covalent: strong
- Metallic: malleable
- Ionic: weaker
- Hydrogen bonds: weakest (individually), but strong collectively.
Water and Its Properties: Composition

- Elemental composition of H₂O
  - Hydrogen: most abundant element in universe
  - Oxygen: 3rd most abundant element
- Hypothesis: H₂O is common throughout the universe

Liquid Solution for Living Systems

- Introduction
  - Life on Earth in water ~4 billion years ago
  - First 3 billion years of life in water alone
  - All life tied to watery medium (plants, animals and microbes)
- Simplicity and complexity of the water molecule
  - Deceptively simple in structure
  - Exquisite in function

There are 6 properties that make water special (and make it especially useful to living organisms)!

1. High heat capacity
2. High heat of vaporization
3. Solvent properties
4. Cohesive & adhesive nature
5. High surface tension
6. Solid is less dense than liquid.

Chemistry of WATER

1. High heat capacity: Water heats up & cools down slower than most liquids. Holds heat longer than most. This buffers the amount of evaporating and freezing that go on in the environment.
2. High heat of vaporization: Evaporation requires a lot of energy. Sweating helps to reduce body heat. Body heat is used as energy to evaporate water. Critter loses body heat, water gains it and evaporates.
3. Solvent properties: Molecules dissolve in water, which allows them to move around more and interact. Water facilitates all chemical reactions in the body.

Chemistry of WATER

5. High surface tension: This is another effect of hydrogen bonds. Water is tough!
6. Solid is less dense than liquid: Ice floats! Bodies of water freeze from the top down.

Water and Its Properties: Polarity

- Composition and structure: a polar molecule

  ![Water, a polar molecule](image)

- Features
  - Attraction is electrical
  - Hydrogen bonding among two or more molecules of H₂O
  - Exquisite properties of H₂O: chemical attractions among molecules because H₂O is a polar molecule
Water and Its Properties: Polarity

Hydrogen bond between water molecules

Generalized Phase Diagram

Phases and Phase Diagram

Water and Its Properties: Liquid State

- Water is liquid over broad range of temperatures
  
  0°C to 100°C

- Comparison with other compounds

<table>
<thead>
<tr>
<th>Compound</th>
<th>Chemical Formula</th>
<th>Freeze</th>
<th>Vapor</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>H₂O</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Ammonia</td>
<td>NH₃</td>
<td>-78</td>
<td>-33</td>
<td>45</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>-182</td>
<td>-164</td>
<td>38</td>
</tr>
</tbody>
</table>

Water and Its Properties: Water and Its Properties: Liquid State

- Significance of broad range of temperatures for water to exist as a liquid
  - Water in a liquid state is not too cold to slow reactions and not too hot to break bonds
  - Could life evolve in another phase (i.e., gas, solid)?

Water's Phase Diagram

- Water's Phase Diagram
Water and Its Properties: Cohesion of Molecules

- Cohesion: $H_2O$ molecules are “sticky”
- Each hydrogen bond last $1 \times 10^{-12}$ seconds
- Constant formation and breakage of bonds: any moment, a substantial number of $H_2O$ molecules are bonded to its neighbors
- Consequence: more structure than other liquids

Water and Its Properties: Freezing

- Water is unusual in that $H_2O$ is less dense as a solid than as a liquid (it floats)
- Mechanism
  - $H_2O$ expands when it solidifies
  - Due to hydrogen bonding
- Consequence
  - Ponds, lakes and ocean freeze from the top down
  - Consequence for living systems?

Water and Its Properties: Solvent of Life

- Water is versatile solvent due to its polarity and dissociation:
  
  \[
  H_2O \rightleftharpoons H^+ + OH^- \\
  H_2O + H^+ \rightleftharpoons H_3O^+ \text{ (hydronium ion)}
  \]
- In pure water, 1 molecule in every $554 \times 10^6$ is dissociated ($10^{-7}$ molar concentration)...pH scale
- Statistically very rare BUT exceedingly important in chemistry of life
- $H^+$ and $OH^-$ are very reactive and affect much of the chemistry of living systems

Plants and Water

- Water enters a plant at root cells.
- Water molecules cling together and adhere to sides of vessels in stems.
- Water evaporates, pulling the water column from the roots to the leaves.

Water and pH

<table>
<thead>
<tr>
<th>$H_2O^+$ Concentration (mole/liters)</th>
<th>pH</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \times 10^{-1}$</td>
<td>0</td>
<td>Neutral</td>
</tr>
<tr>
<td>$1 \times 10^{-7}$</td>
<td>7</td>
<td>Neutral</td>
</tr>
<tr>
<td>$1 \times 10^{-9}$</td>
<td>8</td>
<td>Basic</td>
</tr>
<tr>
<td>$1 \times 10^{-10}$</td>
<td>9</td>
<td>Basic</td>
</tr>
<tr>
<td>$1 \times 10^{-11}$</td>
<td>10</td>
<td>Basic</td>
</tr>
<tr>
<td>$1 \times 10^{-12}$</td>
<td>11</td>
<td>Basic</td>
</tr>
<tr>
<td>$1 \times 10^{-13}$</td>
<td>12</td>
<td>Basic</td>
</tr>
<tr>
<td>$1 \times 10^{-14}$</td>
<td>13</td>
<td>Basic</td>
</tr>
<tr>
<td>$1 \times 10^{-15}$</td>
<td>14</td>
<td>Basic</td>
</tr>
</tbody>
</table>

Water and Solutions: Concentrations

- Concentrations of solutes and solvents
  - Parts per million (ppm) or billion (ppb)
  - Atmosphere and carbon dioxide (370 ppm)
  - Percentage by mass
  - Salinity of ocean water - mass of salts in 1,000 grams of water (35 g in 1,000 g water)
  - Chemistry: molarity of solution
  - # moles of solute dissolved in 1 liter of solvent ($H_2O$)
### iClicker Question

- The fact that solid phase water is less dense than liquid phase water is a function of _________.
  - A: van der Waal forces
  - B: covalent bonding
  - C: isometric bonding between hydrogen ions
  - D: hydrogen bonding
  - E: isomerase inequities

### iClicker Question

- In a water molecule, the bonds between adjacent water molecules last for _____.
  - A: one to several days
  - B: several hours
  - C: several minutes
  - D: several seconds
  - E: small fraction of a second

### iClicker Question

- In the model of the water molecule used in class, the uneven distribution of the oxygen and two hydrogen atoms results in the molecule being _________.
  - A: electrically neutral
  - B: ambivalent
  - C: asymmetrically neutral
  - D: pH 7.0
  - E: asymmetrically charged

### iClicker Question

- In a glass of pure water, a molecule of H$_2$O is ________ than H$^+$ or H$_2$O$^+$ ions.
  - A: less common
  - B: more common
  - C: equally common

### Hierarchy Theory and Emergent Properties of H$_2$O

- Principle of hierarchy theory
- Principle of emergent properties
- Example of H$_2$O in Periodic Table
- *a priori*: combine one atom of O with two atoms of H
  - Emergent properties
    - Liquid
    - Hydrogen bonding and polarity
    - H$^+$ and OH$^-$ in solution
    - Solvent
    - Range of temperature at which liquid
    - Three phases (gas, liquid and solid)
**Question**

Substance A has a pH of 2 and Substance B has a pH of 3. This means that ____.

A. Substance A is more basic than Substance B  
B. Substance B is more acidic than Substance A  
C. Substance A is 10 times more acidic than substance B  
D. Substance B is 10 times more acidic than substance A

**Questions**

A deep lake in Virginia is covered with ice in January. What is the water temperature at the bottom of the lake relative to that of the surface water?

A. warmer  
B. colder

**Question**

How does ocean water in proximity to continents affect the climate of the adjoining land mass?

A. makes climate colder  
B. makes climate warmer  
C. moderates climate (warming if cold, cooling if hot)

**Question**

In the search for life on other planets and in other solar systems, why is the presence and/or absence of water regarded as one of the cardinal indicators of the possibility of life?

A. Because we don't know life any other way.  
B. Because of the special physical and chemical properties of water  
C. All of the above

**Biochemistry: where chemistry and biology meet head-on**

- Living things require millions of chemical reactions within the body, just to survive.  
- Metabolism = all the chemical reactions occurring in the body.  
- Organic molecules:  
  - usually associated with living things.  
  - Always contain CARBON.  
  - “large” molecules, many atoms  
  - Always have covalent bonds.

**Life**

- Water is the environment of life  
- Water a moderately reactive liquid  
- Water, H₂O is a molecule made up of two hydrogen atoms having a relationship with one Oxygen atom  
- About 70% of the body is water
H₂O, sharing amongst unequal atoms

The result is a molecule with electrical polarity

H₂O: A Structured Liquid

Water molecules “play” with each other because of polarity

Pulling Water Molecules Apart

H⁺ and OH⁻ (ions individuals with electrical charge)

Reactivity!!!!

Acids: More and more inequality and ions

Reactivity!!: Charges “play” with the relationships between atoms and molecules

Hydrochloric acid

Chloride ion

Salts: More Ions

Outer Shell

Sharing 1+7 = 8 (Full)

Put NaCl into water and you get ions
Many ions

![Many ions diagram](image)

Eg. NaCl, LiCl, MgCl₂, CaCl₂, FeCl₂

Compartments of H₂O

- Oil and Water (H₂O) don’t Mix
- A compartment is a space that contains water that is different than the water spaces around it
- Two different water compartments next to each other are stored energy
- Stored energy is potential energy: The potential to be the same

How do you make compartments of water that are different next to each other?

Use a schizophrenic molecule oil and water don’t mix

Parts of the phospholipid molecule likes water and parts of likes oil

![Compartment of water diagram](image)

A Compartment of water in the sea of water...eg. A Cell

That is what a battery is

Differences between compartments: Potential ENERGY

You Live on a bunch of ephemeral batteries that constantly need recharging