1

Matter & Energy: Properties of Water, pH, Chemical Reactions

EVPP 110 Lecture
GMU
Dr. Largen
Fall 2003

2 The Properties of Water

3 Water - Its Properties and Its Role in the Fitness of Environment

- ✓importance of water to life
- ✓chemical characteristics of water
  - – polarity and properties associated with it
  - –
  - – dissociation of water molecules

4 **The Properties of Water -**
Water is essential to life

- ✓Importance of **water** to life
  - – covers ¾ of surface of earth
  - – is where life evolved
  - – essential to life on earth
  - – ~ 2/3 of mass of all organisms

5 Figure 3.0 Earth (*Biology*, 6th Ed., Campbell & Reece)

6 **The Properties of Water -**
Chemical Structure of water

- ✓chemical structure of **water (H_2O)**
  - – 2 H atoms covalently bonded to 1 O atom
    - resulting molecule is stable
      - – outer electron shells full
      - – no net charge
      - – no unpaired electrons

7

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9 **The Properties of Water -**
Water is a polar molecule

✓**Water** is a **polar molecule**

– O atom is more electronegative than H atoms

• attracts electrons more strongly than do H atoms

– shared electrons in a water molecule more likely to be found near O nucleus than near the H nuclei,

» partial – charge on O atom

» partial + charge on each H atom

10

11

12 **The Properties of Water -**
Water is a polar molecule

✓**Water** is a **polar molecule**

– water molecule as a whole is neutral

• but partial charges cause molecule to have “poles”

• negative pole

– O end due to partial – charge on O atom

• positive poles

– H ends due to partial + charge on each H atom

13

14 Web/CD Activity 3A:
The Polarity of Water

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15 **The Properties of Water -**
Water’s polarity leads to unusual properties

✓**Water’s polarity** leads to unusual properties that make life possible

– **hydrogen bonds**

– **cohesion**

– **surface tension**

– **temperature moderation**

– **less dense as solid than liquid**

– **versatile solvent**

– **role in acid/base conditions**

16 **The Properties of Water -**
Water’s polarity leads to unusual properties

✓**polarity** of **water molecules**

– causes them interact with each other

–

- this attraction results in formation of weak bonds
  - called **hydrogen bonds**

17 **The Properties of Water -**
Water's polarity leads to unusual properties

✓**hydrogen bonds**

- result when polar molecules interact with one another
  - partial – charge of one molecule is attracted to the partial + charge of another molecule

18 
Figure 3.1 Hydrogen bonds between water molecules (*Biology*, 6th Ed., Campbell & Reece)

19 

20 **The Properties of Water -**
Water's polarity leads to unusual properties

✓**hydrogen bonds**

- individually weak
  -
  -
- cumulatively strong
- form between each water molecule and four of its neighboring molecules
- hydrogen bonds extremely important to biological systems

21 **The Properties of Water -**
Water's polarity leads to unusual properties

✓Like no other <u>common</u> substance on Earth, **water exists in nature in all three physical states** (or phases of matter)

- solid (ice)
- liquid (water)
- gas (water vapor)

22 
Figure 3.x1 Water , liquid, solid, vapor (*Biology*, 6th Ed., Campbell & Reece)

23 
Figure 3.5x1 Ice, water, and steam (*Biology*, 6th Ed., Campbell & Reece)

24 **The Properties of Water -**
Hydrogen bonds make liquid water cohesive

✓**cohesion**

- attraction resulting from polar water molecules being attracted to each other
  - water molecules have a strong tendency to stick together
- much stronger for water than for most other liquids
- of water is important in living world
  - example, trees
    –

25 
Figure 3.2x Trees (*Biology*, 6th Ed., Campbell & Reece)

26 **The Properties of Water -**
Hydrogen bonds make liquid water cohesive

✓**surface tension**

- related to cohesion

– a measure of how difficult it is to stretch or break surface of a liquid
– at air-water interface, all hydrogen bonds in water face downward, causing molecules of water surface to cling together
• polar water molecules are “repelled” by nonpolar molecules in the air

27 **The Properties of Water -**
Hydrogen bonds make liquid water cohesive

✓**surface tension**
– water has highest surface tension of any liquid except for liquid mercury
•

28 
Figure 3.3 Walking on water (*Biology*, 6th Ed., Campbell & Reece)

29 **The Properties of Water -**
Hydrogen bonds make liquid water cohesive

✓**adhesion**
– attraction resulting from polar water molecules being attracted to other polar non-water molecules
•)
– **capillary action**
• tendency of water to rise in small tubes, as a result of cohesive and adhesive forces
•

30 
Figure 3.2 Water transport in plants (*Biology*, 6th Ed., Campbell & Reece)

31 Web/CD Activity 3B: Cohesion of Water
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32 **The Properties of Water -**
Water’s hydrogen bonds moderate temperature

✓**Water** has greater ability to **resist temperature change** than most other substances
– due to its hydrogen bonds

✓**heat**
– amount of energy associated with movement of atoms and molecules in a body of matter

✓**temperature**
– intensity of heat
– average speed of molecules rather than total amount of heat in a body of matter

33 **The Properties of Water -**
Water’s hydrogen bonds moderate temperature

✓Water resists temperature increases
– raising temperature of a substance involves
• adding heat energy to make its molecules move faster
– in water, some of H bonds must first be broken
• to allow the molecules to move more freely
– much of energy added to water is used up in breaking the H bonds
• only a portion of heat energy is available to speed movement of water molecules

34 **The Properties of Water -**
Water’s hydrogen bonds moderate temperature

✓**Water stores heat**
– heat is absorbed as H bonds break

- water absorbs and stores a large amount of heat while warming up only a few degrees

✓**Water cools slowly**

– as water cools, H bonds re-form

- heat energy is released as H bonds form, thus slowing the cooling process

35 **The Properties of Water -**
Water's hydrogen bonds moderate temperature

✓Water resists temperature change

– enables organisms to maintain relatively constant internal temperatures

-

– crucial in stabilizing temperatures on earth

- by storing heat from sun during warm periods, releasing heat during cooler times

36 **The Properties of Water -**
Water's hydrogen bonds moderate temperature

✓Water resists tendency to evaporate or vaporize

– liquids vaporize when some of their molecules move fast enough to overcome attractions that keep molecules close together

- heating a liquid increases vaporization by increasing energy of molecules
  - providing some of molecules with enough energy to escape

37 **The Properties of Water -**
Water's hydrogen bonds moderate temperature

✓Water resists tendency to vaporize

– large amount of energy is required to change one gram of liquid water into a gas

– water's resistance to vaporization results from the hydrogen bonding of its molecules

- transition of water from a liquid to a gas requires input of energy to break hydrogen bonds
  - source of such energy can be surface of substance on which water is located

38 **The Properties of Water -**
Water's hydrogen bonds moderate temperature

✓evaporation of water from surfaces causing a cooling of that surface

– enables organisms to dispose of excess heat by **evaporative cooling**

- organism gives up some heat energy to break H bonds in the water molecules
  - such molecules then have enough heat energy to escape
    - » they take that heat energy with them when they go

39 Figure 3.4 Evaporative cooling (*Biology*, 6th Ed., Campbell & Reece)

40 **The Properties of Water -**
Ice is less dense than liquid water

✓Water is **less dense as a solid than as a liquid**

– most substances become more dense as temperature decreases

– water is most dense at 4°C then becomes less dense as temperature decreases below that point

– hydrogen bonds in liquid water are unstable

- they constantly break and re-form

– hydrogen bonds in ice are stable

- each molecule bonds to 4 neighbors forming a 3-D crystal

41 Figure 3.5 The structure of ice (Layer 1) (*Biology*, 6th Ed., Campbell & Reece)

42 Figure 3.5 The structure of ice (Layer 2) (*Biology*, 6th Ed., Campbell & Reece)

43 **The Properties of Water -**
Ice is less dense than liquid water

✓liquid water expands (becomes less dense) as it freezes because
- – H bonds joining water molecules in crystalline lattice keep molecules far enough apart to give ice a density about 10% less than density of water
  - • less dense frozen water (ice) floats on more dense cold, unfrozen water

44 Figure 3.5x1 Ice, water, and steam (*Biology*, 6th Ed., Campbell & Reece)

45 **The Properties of Water -**
Ice is less dense than liquid water

✓Ice is less dense than liquid water
- – frozen water floats on liquid water
  - • extremely important factor in enabling life to appear, survive and evolve
    - – if ice were more dense than water it would sink
      - » all ponds, lakes, oceans would freeze solid from the bottom to surface making life impossible

46 Figure 3.6x2 Ice floats and frozen benzene sinks (*Biology*, 6th Ed., Campbell & Reece)

47 **The Properties of Water -**
Ice is less dense than liquid water

✓Ice is less dense than liquid water
- – since ice floats on water instead of sinking
  - • a body of deep water freezes at top, becoming covered with floating ice
    - – ice insulates liquid water below it
      - » preventing water from freezing solid
      - » allowing certain animals and plants to survive below icy surface

48 Figure 3.6 Floating ice and the fitness of the environment (*Biology*, 6th Ed., Campbell & Reece)

49 Figure 3.6x1 Floating ice and the fitness of the environment: ice fishing (*Biology*, 6th Ed., Campbell & Reece)

50 Water - Its Properties and Its Role in the Fitness of Environment

✓ importance of water to life
✓ chemical characteristics of water
- – polarity and properties associated with it
  - • hydrogen bonds
  - • cohesion
  - • surface tension
  - • temperature moderation
  - • less dense as solid than as liquid
- – **dissociation of water molecules**
  - • **water is versatile solvent**
  - • **role in acid/base conditions**
  - • **effect of pH on living organisms**

51 **The Properties of Water -**
Water is a versatile solvent

✓ **Solution**
- – liquid, that is uniform throughout (homogeneous), consisting of a mixture of two or more substances
- – **solvent**
  - • substance in a solution that serves as dissolving agent
  - • usually a liquid, capable of dissolving one or more other substances
- – **solute**

- substance which is dissolved by solvent

✓ solution that has water as its solvent is called an **aqueous solution**

52 **The Properties of Water -**
Water is a versatile solvent

✓ **Water is a versatile solvent**

– dissolves an enormous variety of solutes necessary for life
- water is solvent in all cells
  – .

– results from polarity of its molecules
- solutes whose charges or polarity allow them to stick to water molecules will dissolve in water, forming an aqueous solution

53 **The Properties of Water -**
Water is a versatile solvent

✓ **Water is a versatile solvent**

– consider how a crystal salt dissolves in water
- Na^+ and Cl^- ions at surface of salt crystal have affinities for different parts of water molecules
  – Na^+ ions attract - area of H_2O at O
  – Cl^- ions attract + areas at H's
- water molecules surround and separate Na^+ and Cl^- ions (hydration shell)
  – causing salt crystal to dissolve

54 Figure 3.7 A crystal of table salt dissolving in water (*Biology*, 6th Ed., Campbell & Reece)

55 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓ Most water molecules remain intact in aqueous solutions within living organisms

– but some water molecules actually break apart in a process called **dissociation** or **ionization**
- formation of ions when covalent bonds in a water molecule break spontaneously
  –

56 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓ Two types of ions result from dissociation of water molecules (H_2O)

– **hydrogen ions (H^+)** with + charge

– **hydroxide ions (OH^-)** with – charge

57 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓ Two types of ions result from dissociation

– **hydrogen ions (H^+)** with + charge result
- when one of protons (from hydrogen atom nuclei) dissociate from the rest of the molecule
-

58 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓Two types of ions result from dissociation

– **hydroxide ions (OH^-)** with - charge results

• from the rest of the dissociated water molecule

– which has retained shared electron from covalent bond, is negatively charged and forms a hydroxide ion, OH^-

59 Unnumbered Figure (page 47) Dissociation of water molecule to hydronium and hydroxide ions (*Biology*, 6th Ed., Campbell & Reece)

60

61 # Web/CD Activity 3C: Dissociation of Water Molecules

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62 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓Hydrogen and hydroxide ions result from spontaneous dissociation of water molecules in aqueous solutions

– right balance of these two ions is required for proper functioning of chemical processes within organisms

• the balance between these two ions is described and measured in terms of **acids**, **bases** and **pH scale**

63 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓**acid**

– any substance that dissociates in water to increase concentration of H^+ ions

✓**base** (or **alkali**)

– any substance that combines with H^+ ions when dissolved in water

✓**neutral**

– any substance in which concentrations of H^+ ions and OH^- ions are equal

64 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓ **pH scale**

– used to measure acidity or alkalinity of a solution

• pH stands for" potential hydrogen"

– the negative logarithm of hydrogen ion ($[H^+]$) concentration in solution

» (negative logarithm of 10^{-7} equals 7, therefore pH of pure water is 7)

65 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓**acid**

– any substance that dissociates in water to increase concentration of H^+ ions

– stronger an acid is, the more H^+ ions it produces

– acidic solutions have pH values below 7

– strong hydrochloric acid (HCl), abundant in your stomach, ionizes completely in water to H^+ and Cl^- ions, has a pH of 1

66

67 **The Properties of Water -**

The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓**base**

– any substance that combines with H^+ ions when dissolved in water

– by combining with H^+ ions, a base lowers H^+ ion concentration in solution

– basic, or alkaline, solutions have pH values above 7

– strong bases, such as sodium hydroxide (NaOH), have pH values of 12 or more

68

69 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓**Neutral**

– any substance in which concentrations of H^+ ions and OH^- ions are equal

– neutral solutions have a pH value of 7

- at 25°C, a liter of pure water contains 1/10,000,000 (or 10^{-7}) mole of H^+ ions
- negative logarithm of 10^{-7} equals 7, and therefore the pH of pure water is 7

70

71 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓pH inside almost all cells, and in fluid surrounding cells, is fairly close to 7

– even a slight change in pH can be harmful

- biological fluids contain **buffers** that resist changes in pH

72 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓**buffer**

– substance that resists changes in pH by

- accepting H^+ ions when they're in excess
- donating H^+ ions when they're depleted

– acts as a reservoir for hydrogen (H^+) ions

- takes H^+ ions from solution when their concentration increases
- donates H^+ ions to solution when their concentration falls

– buffers are not foolproof

73

74 **The Properties of Water -**
The chemistry of life is sensitive is sensitive to acidic and basic conditions

✓important that cell maintain a constant pH level

– pH of an organism is kept at relatively constant pH by **buffers**

- within organisms most buffers act as pairs of substances
  - one an acid and one a base
- example
  –

75 Web/CD Activity 3D:

Acids, Bases, and pH

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76 **The Properties of Water -**
Acid precipitation threatens the environment

- ✓changes in pH can harm living organisms
- ✓changes in pH of environment can have drastic effects
  - – **acid precipitation** (rain, fog, snow) can cause changes in pH of environment
    - pH changes can kill fish in lake, trees in forests, affect human health, erode buildings

77 
Figure 3.10 The effects of acid precipitation on a forest (*Biology*, 6th Ed., Campbell & Reece)

78 
Figure 3.10x2 Acid rain damage to statuary, 1908 & 1968 (*Biology*, 6th Ed., Campbell & Reece)

79 **The Properties of Water -**
Acid precipitation threatens the environment

- ✓**acid precipitation** (rain, fog, snow)
  - – precipitation with a pH below 5.6
    - rain with pH of 2-3, more acidic than vinegar, recorded in eastern US
    - fog with pH1.7, nearly acidic as human stomach digestive juices, recorded downwind from LA

80 **The Properties of Water -**
Acid precipitation threatens the environment

- ✓**acid precipitation** (rain, fog, snow)
  - – results mainly from presence in air of sulfur oxides and nitrogen oxides
    - which result mostly from the burning of fossil fuels in factories and automobiles
      - – coal, oil and gas are fossil fuels
  - – complex environmental problem with no easy solution

81 
Figure 3.10x1 Pulp mill (*Biology*, 6th Ed., Campbell & Reece)

82 Rearrangements of Atoms

83 **Rearrangements of Atoms -**
Chemical reactions rearrange matter

- ✓**chemical reactions** lead to chemical changes in matter
  - – are essence of chemistry and life
- ✓all chemical reactions involve
  - – shifting of atoms from one molecule or ionic compound to another
    - via formation and breaking of chemical bonds
  - – without any change in number or identity of atoms

84 **Rearrangements of Atoms -**
Chemical reactions rearrange matter

- ✓all chemical reactions involve
  - – **reactants**
    - original molecules before a chemical reaction starts
  - – **products**

- molecules resulting from chemical reaction

85 **Rearrangements of Atoms -**
Chemical reactions rearrange matter

✓chemical reactions can be described by **chemical equations**

– **reactants**
- written on left side of equation

– **products**
- written on right side of equation

– **arrow** (instead of =)between "reactants" side and "products" side
- means **"*yields*"**
- indicates direction in which reaction tends to proceed

86 **Rearrangements of Atoms -**
Chemical reactions rearrange matter

✓**chemical equations**

– example: $2H_2 + O_2 \rightarrow 2H_2O$

– reactants products

– same numbers of H and O atoms appear on both left and right hand side of arrow but are grouped differently
- (H-H) + (H-H) + (O-O) = (H-O-H) + (H-O-H)
- 4 H, 2 O = 4 H, 2 O
- 2 molecules of H plus 1 molecule of O yields 2 molecules of water

87

88 Figure 2.19 A molecular mimic (*Biology*, 6th Ed., Campbell & Reece)

89 **Rearrangements of Atoms -**
Chemical reactions rearrange matter

✓**chemical equations**

– can proceed in two directions
- **forward** = to the right →
- **reverse** = to the left ←

– when rates of forward and reverse reactions are equal, reaction has reached **equilibrium**

90 **Rearrangements of Atoms -**
Chemical reactions rearrange matter

✓**chemical reactions**

– organisms carry out a great number of chemical reactions, most involving carbon, that rearrange matter in significant ways

– examples
- photosynthesis
  - $6CO_2 + 6H_2O + \text{energy} \rightarrow 6O_2 + C_6H_{12}O_6$
  - 6C, 12H, 18O → 6C, 12H, 18O
- production of vitamin A in human cells
  - $C_{40}H_{56} + O_2 + 4H \rightarrow 2C_{20}H_{30}O$
  - beta-carotene vitamin A
  - 40C, 2O, 60H → 40C, 2O, 60H

91

92 The End