1

The Chemical Basis of Life

Bio 103 Lecture
GMU
Dr. Largen

2 Sections

- ✓Atoms & molecules
- ✓Properties of Water
- ✓Rearrangements of Atoms

3 Atoms and Molecules

4 **Atoms & Molecules -**
Biological function starts at chemical level

- ✓Knowledge of functions of organisms
  - **reductionist approach**
    - scientific approach
      - » whole best understood by studying parts

5 **Atoms & Molecules -**
Biological function starts at the chemical level

- ✓to understand chemical structure and function
  - start small
    - structures at each level are combined into each higher level
  - *note the hierarchical aspect of this idea*

6 **Atoms & Molecules -**
Biological function starts at the chemical level

✓matter in all living things
- made up of chemicals
- structure and function
  - interrelated at every level

7 **Atoms & Molecules -**
Biological function starts at the chemical level

✓example
- certain **atoms** come together to form the complex **molecule** chlorophyll
- many chlorophyll molecules are located in **organelles** called chloroplasts
- many chloroplasts are located in the **cells** of photosynthetic **tissues** in structures (**organs**) such as **leaves** of **plants**

8 
Figure 2.1 The hierarchy of biological order from atom to organism (*Biology*, 6th Ed., Campbell & Reece)

9 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓life is composed of **matter**
✓matter is composed of chemical **elements**

10 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**Matter**
–
- **mass** – the amount of a substance
  –
  –
- **weight** – force gravity exerts on substance
  –
  –

11 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**Matter**
– three states (phases) on earth

- **gas**
- **liquid**
- **solid**

12 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓Matter
– **gas**
•

– liquid
– solid

13 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓Matter
– gas
– **liquid**
•

– solid

14 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓Matter
– gas
– liquid
– **solid**
•

15 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓chemical **element**
– substance which cannot be broken down into any other substance
•

– each element consists of one type of atom
•

16 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**naturally occurring elements**
– 92 naturally occurring
•

✓**man-made elements**
– additional 12 - 17 man-made elements
•
•

17 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**distribution of elements** (non-living vs. living)
– in crust of earth (non-living)
• 9 elements constitute ~99% (by mass) of the earth's crust
–

»

18 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**distribution of elements** (non-living vs. living)
– in living organisms
• of 92 naturally occurring elements
– ~ 25 are essential to life
» 14 of which are found in organisms in any more than **trace** (>0.01%) amounts
» **trace elements**

»

19 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓ of the 25 elements essential to life
– 11 are found in > than trace amounts
• 4 make up ~96% of human body
– **C**
– **H**
– **O**

- **N**

- 7 make up remaining ~4% of human body
  - **Ca, P, K, S, Na, Cl,Mg**

20 Table 2.1 Naturally Occurring Elements in the Human Body (*Biology*, 6th Ed., Campbell & Reece)

21 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓Each element has a symbol
-
  -
  - examples
    - gold (Au) - from Latin word *aurum*
    - oxygen (O) - from English word *oxygen*

22 **Atoms & Molecules -**
Elements can combine to form compounds

✓Elements combine to form molecules and compounds
- **element**
- **molecule**
- **compound**

23 **Atoms & Molecules -**
Elements can combine to form compounds

✓element
-
- can't be broken down
  -
- atoms with same atomic number
  -

✓molecule

✓compound

24 **Atoms & Molecules -**
Elements can combine to form compounds

✓element

✓molecule
- group of atoms of same type held together
  -
- example
  - molecule of oxygen (O_2)

✓compound

25 **Atoms & Molecules -**
Elements can combine to form compounds

✓element
✓molecule
✓**compound**
– molecule containing atoms of 2 or more elements combined in a fixed ratio
– example
• water
– H_2O
–

26 **Atoms & Molecules -**
Elements can combine to form compounds

✓**Compounds**
– more common than pure elements
•
– example., table salt (NaCl)
– in living organisms
• contain at least 3 or 4 different elements
– mainly C, H, O, N

27 Figure 2.2 The emergent properties of a compound (*Biology*, 6th Ed., Campbell & Reece)

28 **Atoms & Molecules -**
Elements can combine to form compounds

✓**Compounds**
– described by combination of symbols and numerals
• **chemical formula (**or **molecular formula)**
• **structural formula**

29 **Atoms & Molecules -**
Elements can combine to form compounds

✓**chemical formula** or **molecular formula**
– consists of chemical symbols and numbers
• indicates types & number (subscript) of atoms present
•
– example, chemical formula for water is H_2O
• no number subscript when single atom present
•

30 **Atoms & Molecules -**
Elements can combine to form compounds

✓**structural formula**

– shows arrangement of atoms

• in additional to type and number

– example, structural formula for water is H-O-H

31 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓Each element consists of one kind of **atom**

–

– name **"atom**" comes from a Greek word meaning "indivisible"

• **atom** is smallest unit of matter

–

32 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**atoms**

– composed of many types of subatomic particles

– **nucleus** contains

• **protons**

• **neutrons**

– **electrons** orbit the nucleus

– others particles

• discussed primarily by physicists

33

34 **Web/CD Activity 2B:**
Structure of the Atomic Nucleus

35 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**protons (p)**

– type of charge =

– where found =

– relative mass =

36

37 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**neutrons (n)**

– type of charge =

– where found =

– relative mass =

38

39 **Atoms & Molecules -**

Atoms consist of protons, neutrons and electrons

✓**electrons (e)**

– type of charge =

– relative mass =

– where found =

40

41 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**Electron orbitals** can be

– various shapes

- usually illustrated as concentric circles
-

✓electrons orbit nucleus

– nearly at speed of light

-

-

42 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**Electron orbitals**

– arrangement of electrons in their orbits is key to chemical behavior of atom

– will return to this point shortly

43 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓All atoms of a particular element

– have same unique number of protons

– known as the element's

- **atomic number**
  – number of protons in atom's nucleus
    »
  – top number in box for element in periodic table

44

45 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓atom's **atomic mass** (also called **atomic weight** or **mass number**)

– equal to sum of masses of atom's protons & neutrons

- measured in **daltons**
  –
  –
- bottom number in box for element in periodic table

46

47 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓ **isotopes**

– atoms of same element that vary in neutron number and atomic mass

•

– isotopes of carbon

• carbon ^{12}C

–

• carbon ^{13}C

–

• carbon ^{14}C

–

48 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓ **Isotopes** can be

– **stable**

• nuclei remain permanently intact

–

– **unstable** (or **radioactive**)

• nuclei decays spontaneously, giving off particles and energy

–

49 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓ **Isotopes** can be

– **unstable** (or **radioactive**)

• nucleus tends to break up into elements with lower atomic numbers

– emits significant amount of energy, called **radioactive decay**

» **radioactive isotopes**

»

50 **Atoms & Molecules -**
Radioactive isotopes can help us or harm us

✓ **Radioactive isotopes** can be

– harmful to life

•

•

•

•

51 **Atoms & Molecules -**
Radioactive isotopes can help us or harm us

✓ **Radioactive isotopes** can have

– beneficial uses

-
-
-
-

52 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓Electrons
- – orbit nucleus of atom
- – arrangement in orbits is key to chemical behavior of atom
- – vary in amount of energy they possess
  - farther nucleus, greater its energy

53 Figure 2.9 Energy levels of an atom's electrons (*Biology*, 6th Ed., Campbell & Reece)

54 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓electrons are far from nucleus
- – analogy:
- – result
  -
  -
  -

55 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓electrons in atom occur only at certain energy levels
- – called **electron shells** (or **electron energy levels**)

✓atoms may have 1, 2 or more electron shells
- –
- –
- –

56 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓we'll consider first four **electron energy shells**
- – covers most biologically significant elements
- – first, innermost energy shell asdasdasda
  - can accommodate only 2 electrons
  -
- – second, third, fourth energy shells
  - can each accommodate 8 electrons
  -

57

58 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓atom has # of electron shells needed accommodate its number of electrons

- atom with 6 electrons (C) has 2 shells
  - 2 electrons in innermost shell
  - 4 electrons in outermost shell
- atom with 11 electrons (Na) has 3
  - 2 electrons in innermost shell
  - 8 electrons in second shell
  - 1 electron in outermost shell

59 
Figure 2.11 Electron orbitals ((*Biology*, 6th Ed., Campbell & Reece)

60 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓ Energy is required to keep electrons in their orbits

– electrons have potential energy of position

- more potential energy in outermost shells than in innermost shells
  –

  –

61 
Figure 2.9 Energy levels of an atom's electrons (*Biology*, 6th Ed., Campbell & Reece)

62 Web/CD Activity 2C:
Electron Arrangement

63 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓number of electrons in outermost shell determines chemical properties of element

– partially full outer shells = reactive

•

– full outer shells = unreactive (inert)

64 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓example

– hydrogen (H) is highly reactive

- one shell, only one electrons
  –

  –

65

66 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

- ✓example
  - helium (He) is highly unreactive (inert)
    - one shell, two electrons
      -
      -

67

68 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

- ✓How does a chemical reaction enable an atom to fill its outer electron shell?
  - 2 atoms w/incomplete outer shells react
    - each atom gives up or acquires electrons
      -
    - results in atoms being held together by **chemical bonds**

69 Figure 2.10 Electron configurations of the first 18 elements (*Biology*, 6th Ed., Campbell & Reece)

70 Web/CD Activity 2D:
Build an Atom

71 **Atoms & Molecules -**
Chemical bonds

- ✓strong chemical bonds
  - **ionic bonds**
  - **covalent bonds**
    - **nonpolar covalent bonds**
    - **polar covalent bonds**
- ✓weak chemical bonds
  - **hydrogen bonds**

72 **Atoms & Molecules -**
Chemical bonds

- ✓strong chemical bonds
  - **ionic bonds**
  - covalent bonds
    - nonpolar covalent bonds
    - polar covalent bonds
- ✓weak chemical bonds

– hydrogen bonds

73 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓electron transfer between 2 atoms moves 1 unit of negative charge from one atom to other

– original atom now has +1
  •
– recipient atom now has charge of -1
  •
  •

74 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓**ions**

– atoms in which number of electrons does not equal number of protons
  • carry a net electrical charge (+ or -)
– types of ions
  • cations
  • anions

75 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓**cation**

– atom with net positive charge (+)
  •
–

– example:
  • sodium (Na) atom losses an electron, becomes sodium ion, or cation (Na^+), with charge of +1

76

77 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓**Anion**

– atom with net negative charge (-)
  •
–
– example
  • chlorine (Cl) atom, gains one electron, becomes chlorine ion, or anion (Cl^-), with charge of -1

78

79 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓two ions with opposite charge attract each other

– attraction called an **ionic bond**

• resulting compound is electrically neutral

80 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓**ionic bond**

– results from transfer of electron from one atom to another atom

• resulting in two ions

– cation

– anion

– oppositely charged ions are attracted to each

•

– resulting compound is electrically neutral

81 Figure 2.14 Electron transfer and ionic bonding (*Biology*, 6th Ed., Campbell & Reece)

82 Figure 2.15 A sodium chloride crystal (*Biology*, 6th Ed., Campbell & Reece)

83 Web/CD Activity 2G:
Ionic Bonds

84 **Atoms & Molecules -**
Chemical bonds

✓strong chemical bonds

– ionic bonds

– **covalent bonds**

• nonpolar covalent bonds

• polar covalent bonds

✓weak chemical bonds

– hydrogen bonds

85 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓**covalent bond**

– occurs when two atoms share one or more pairs of outer shell electrons

• results in both atoms having a full outer electron shell

–

–

86 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓why is a covalent bond so stable?

–

– resulting molecule (compound)

• has no net electrical charge

- outer shells are full
- no free electrons to form bonds

87 Figure 2.12 Covalent bonding in four molecules (*Biology*, 6th Ed., Campbell & Reece)

88 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓More than one covalent bond can form between two atoms
- single covalent bond
- double covalent bond
- triple covalent bond

89 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓**single covalent bond**
- one pair of electrons shared by two atoms
- represented by
  -
  - example, H - H
- least strong of covalent bonds

90

91 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓**double covalent bond**
- two pairs of electrons shared by two atoms
  - represented by
    -
    - example, O=O
- stronger than single covalent bond
  -

92

93 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓**triple covalent bond**
- three pairs of electrons shared by two atoms
  - represented by
  -
  - example, N ≡ N
- strongest covalent bonds
  -

94 Web/CD Activity 2E:
Covalent Bonds

95 **Atoms & Molecules -**

Covalent bonds, the sharing of electrons, joins atoms into molecules

✓covalent bond energy

– forming bond requires input of energy

• energy is stored in bond

– breaking bond results in release of energy

• released energy becomes available to do work

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Atoms & Molecules -
Covalent bonds, polar versus non-polar

✓Atoms in a covalently bonded molecule

– in tug-of-war for shared electrons

✓**electronegativity**

– measure of attraction (affinity) for shared electrons in covalent bond

• stronger electronegativity = stronger pull on shared electron

97 **Atoms & Molecules -**
Chemical bonds

✓strong chemical bonds

– ionic bonds

– covalent bonds

• **nonpolar covalent bonds**

• polar covalent bonds

✓weak chemical bonds

– hydrogen bonds

98 **Atoms & Molecules -**
Covalent bonds, polar versus non-polar

✓Because of concept of electronegativity**, covalent bonds** can be divided into two categories

– **nonpolar covalent bonds**

– **polar covalent bonds**

99 **Atoms & Molecules -**
Covalent bonds, polar versus non-polar

✓**nonpolar covalent bond**

– covalent bond between atoms with similar electronegativity

– result, electrons are shared equally between two atoms

– examples

• O_2

• H_2

• CH_4 (methane)

100 Figure 2.12 Covalent bonding in four molecules (*Biology*, 6th Ed., Campbell & Reece)

101 **Atoms & Molecules -**
Chemical bonds

✓strong chemical bonds
- ionic bonds
- covalent bonds
  - nonpolar covalent bonds
  - **polar covalent bonds**

✓weak chemical bonds
- hydrogen bonds

102 **Atoms & Molecules - Covalent bonds, polar versus non-polar**

✓**polar covalent bond**
- covalent bond between atoms that differ in electronegativity
  - atom with greater electonegativity pulls shared electrons closer
- results in bond has two dissimilar ends
  - "poles", with partial + and partial - charges
- resulting molecules are said to be "polar"
- example = H_2O

103 Figure 2.13 Polar covalent bonds in a water molecule (Biology, *6th Ed., Campbell & Reece)*

104 Web/CD Activity 2F: Nonpolar and Polar Molecules

105 **Atoms & Molecules - Chemical bonds**

✓strong chemical bonds
- ionic bonds
- covalent bonds
  - nonpolar covalent bonds
  - polar covalent bonds

✓weak chemical bonds
- **hydrogen bonds**

106 **Atoms & Molecules - Hydrogen bonds**

✓**hydrogen bonds**
- result when polar molecules interact with one another
- partial – charge of one molecule is attracted to the partial + charge of another molecule
- in the case of water:
  - oxygen is very electronegative
  -

107 Figure 2.16 A hydrogen bond (*Biology*, 6th Ed., Campbell & Reece)

108 Web/CD Activity 2H:

Hydrogen Bonds

109 The Properties of Water

110 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

111 The Properties of Water - Water is essential to life

- ✓Importance of **water** to life
  - – covers ¾ of earth's surface
  - – where life evolved
  - – essential to life
  - – makes up ≥ 2/3 mass of all organisms

112 

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

113 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

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115 

116 The Properties of Water - Water is a polar molecule

- ✓**Water** is a **polar molecule**
  - – O atom more electronegative than H atoms,
    - attracts electrons more strongly
  - – shared electron pair closer to O nucleus than to H nuclei, results in
    - – partial – charge at O ends
    - – partial + charge at each H atom

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118

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

✓**Water** is a **polar molecule**

– water molecule as whole is neutral,

- but partial charges cause molecule to have “poles”
- negative pole
  - O end
    »
- positive poles
  - H ends
    »

120

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

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

✓**Water’s polarity**

– leads to unusual properties

- make life, as we know it, possible

– **hydrogen bonds**
– **cohesion**
– **surface tension**
– **temperature moderation**
– **less dense as solid than liquid**
– **versatile solvent**
– **role in acid/base conditions**

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

✓**polarity** of **water molecules**

– makes them interact with each other

-
-

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

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

✓**hydrogen bonds**

– result when polar molecules interact with one another

-

•

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

126

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

✓**hydrogen bonds**

– individually very weak

• form and break readily

•

– cumulatively strong

– each water molecule forms hydrogen bonds with maximum of four neighboring water molecules

–

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

✓**water exists in nature in all three physical states** (or phases of matter)

✓

– solid (ice)

– liquid (water)

– gas (water vapor)

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

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

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

✓**cohesion**

– results from attraction between polar water molecules

–

– stronger for water than for most other liquids

– important in living world

• example,transport of water from roots to leaves in trees

–

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

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

✓Related to cohesion is **surface tension**

– measure of how difficult it is to stretch or break the surface of a liquid

– results from orientation of hydrogen bonds at air-water interface

•

•

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

✓**surface tension**

– of water higher than any liquid except liquid mercury

•

135 

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

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

✓**adhesion**

– results from attraction between polar water molecules and polar non-water molecules

• such as glass

• **capillary action**

– tendency of water to rise in small tubes

»

– example, xylem vessel walls in plants

137 

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

138 Web/CD Activity 3B: Cohesion of Water

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

✓ability to **resist temperature change**

– greater in H2O than most other substances

• **heat**

– amount of energy associated with movement of atoms and molecules

• **temperature**

– intensity of heat

– average speed of molecules rather than total amount of heat

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

✓Water resists temperature increases

– raising temperature of substance involves adding heat energy

• results in molecules moving faster

– in water

• some H bonds must first be broken to allow molecules to move more freely

• much of added energy used to break H bonds

– only a portion of heat energy is available to increase movement of water molecules

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

✓**Water stores heat**

– heat is absorbed as H bonds break

• water warms only a few degrees

–

✓**Water cools slowly**

– as water cools, H bonds re-form

• releasing some of stored energy as heat

– slows cooling process
–

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

✓Water resists temperature change
– organisms can maintain a relatively constant internal temperatures
•

– crucial in stabilizing temperatures on earth
•

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

✓Water resists tendency to evaporate or vaporize
– liquids vaporize when molecules move fast enough

• heating a liquid increases vaporization
–
–

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

✓Water resists tendency to vaporize
– large amount of energy required to change one gram of liquid water into a gas
– resistance to vaporization results from hydrogen bonding of its molecules
• transition from a liquid to a gas requires input of energy to break hydrogen bonds
–

145 **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 water molecules
– molecules then have enough heat energy to escape
» take heat energy with them when they go

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

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

✓Water **less dense as a solid than as a liquid**
– most substances, density ↑ as temp ↓
– water most dense at 4°C
•
– hydrogen bonds in liquid water are unstable
•
– hydrogen bonds in ice are stable
•

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

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

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

✓liquid water expands (becomes less dense) as it freezes

– H bonds btwn water molecules keep them far enough apart to give ice a density of ~ 10% less than density of liquid water

– less dense frozen water (ice) floats on more dense cold, unfrozen water

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

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

✓Ice is less dense than liquid water

– ability of frozen water to float 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

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

154 **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

•

• ice insulates liquid water

–

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

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

157 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**

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

✓ **solution**

– liquid, uniform throughout (homogeneous)

• a mixture of two or more substances

✓ **solvent**

– substance in solution that serves as dissolved agent

•

✓ **solute**
- substance which is dissolved by solvent

✓ **aqueous solution**
- solution that has water as its solvent

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

✓ **Water is a versatile solvent**
–
- water is solvent in all cells

– results from polarity of its molecules
-

160 **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

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

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

✓ Most water molecules remain intact in aqueous solutions within living organisms
– some break apart in a process called **dissociation** or **ionization**
- formation of ions when covalent bonds in a water molecule break spontaneously
  –

163 **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

164 **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 rest of molecule

165 **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

- rest of dissociated water molecule, which retains shared electron from covalent bond, is negatively charged and forms a hydroxide ion, OH^-

166 
Unnumbered Figure (page 47) Dissociation of water molecule to hydronium and hydroxide ions (*Biology*, 6th Ed., Campbell & Reece)

167 
Unnumbered Figure (page 47) Dissociation of water molecule to hydronium and hydroxide ions (*Biology*, 6th Ed., Campbell & Reece)

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

www.campbellbioogy.com

169 **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
- proper balance is required for proper functioning of chemical processes within organisms
  - this balance described and measured terms of **acids**, **bases** and **pH scale**

170 **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

171 **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
- = negative logarithm of hydrogen ion ($[H^+]$) concentration in solution

172 **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 = more H^+ ions it produces
- have pH values below 7
- hydrochloric acid (HCl) ionizes completely in water to H^+ and Cl^- ions, has a pH of 1

173 

174 **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
- combining with H^+ ions lowers H^+ ion concentration
- have pH values above 7
- strong bases, such as sodium hydroxide (NaOH), have pH values of 12 or more

175

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

✓**Neutral**

– any substance in which H^+ ions conc. = OH^- ions conc.

– 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 pH of pure water is 7

177

178 **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 ~ 7

– slight change in pH can be harmful

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

179 **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

- accepts H^+ ions when they're in excess
- donates H^+ ions when they're depleted

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

-
-

–

180

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

✓Cells need to maintain a constant pH level

– pH kept at a relatively constant pH by **buffers**

- most buffers act as pairs of substances,
  –
- example, key buffer in human blood is an acid-base pair consisting of carbonic acid (acid) and bicarbonate (base)

182 Web/CD Activity 3D:
Acids, Bases, and pH

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

✓changes in the pH of the environment can have drastic effects

– **acid precipitation** (rain, fog, snow) can cause changes in pH of environment

-

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

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

186 **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, recorded in eastern US
    - fog with pH 1.7,recorded downwind from LA

187 **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
    - result from burning of fossil fuels in factories and automobiles
      - – coal, oil and gas are fossil fuels
  - – complex environmental problem with no easy solution

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

189 # Rearrangements of Atoms

190 **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
    - forming or breaking chemical bonds
    - without change in number or identity of atoms involved

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

- ✓all chemical reactions involve
  - – **reactants**
    - original atoms/molecules present before reaction
  - – **products**
    - atoms/molecules resulting from reaction

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

- ✓chemical reactions can be described by **chemical equations**
  - – **reactants**
    - left side of equation
  - – **products**
    - right side of equation
  - – **arrow** (instead of =)between “reactants” side and “products” side
    - means **“*yields*”**

- indicates direction in which reaction tends to proceed

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

✓**chemical equations**

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

– reactants products

– same numbers H & O atoms on both left & right side of arrow, 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

– (note: organisms can't make water from H & O)

194

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

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

✓**chemical equations**

– can proceed in two directions

- **forward** = to right →
- **reverse** = to left ←

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

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

✓ **chemical reactions**

– organisms carry out many chemical reactions

- most involve carbon
  –

– examples

- 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

198

199 The End