The Threat of Acid Precipitation  Acid precipitation, rain, snow, or fog with a pH lower than normal (pH 5.6), is due to the reaction of water in the atmosphere with the sulfur oxides and nitrogen oxides released by the combustion of fossil fuels. Aquatic life is damaged by acid precipitation, and lowering the pH of the soil solution affects the solubility of minerals needed by plants.

Word Roots

kilo- = a thousand (kilocalorie: a thousand calories)
hydro- = water; -philo = loving; -phobos = fearing
(hydrophilic: having an affinity for water; hydrophobic: having an aversion to water)

<table>
<thead>
<tr>
<th>Property</th>
<th>Explanation of Property</th>
<th>Example of Benefit to Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. cohesion</td>
<td>Hydrogen bonds hold molecules together and adhere them to hydrophilic surface.</td>
<td>b.  Water pulled up plant</td>
</tr>
<tr>
<td>High specific heat</td>
<td>c.</td>
<td>Temperature changes in environment and organisms are moderated.</td>
</tr>
<tr>
<td>d.</td>
<td>Hydrogen bonds must be broken for water to evaporate.</td>
<td>e.</td>
</tr>
<tr>
<td>f.</td>
<td>Water molecules with high kinetic energy evaporate; remaining molecules are cooler.</td>
<td>g.</td>
</tr>
<tr>
<td>Ice floats</td>
<td>h.</td>
<td>i.</td>
</tr>
<tr>
<td>j.</td>
<td>k.</td>
<td>Most chemical reactions in life involve solutes dissolved in water.</td>
</tr>
</tbody>
</table>

Test Your Knowledge

MULTIPLE CHOICE: Choose the one best answer.

1. Each water molecule is capable of forming
   a. one hydrogen bond.
   b. three hydrogen bonds.
   C. four hydrogen bonds.
   d. two covalent bonds and two hydrogen bonds.
   e. two covalent bonds and four hydrogen bonds.
2. The polarity of water molecules
   a. promotes the formation of hydrogen bonds.
   b. helps water to dissolve nonpolar solutes.
   c. lowers the heat of vaporization and leads to evaporative cooling.
   d. creates a crystalline structure in liquid water.
   e. does all of the above.
3. What accounts for the movement of water up the vessels of a tall tree?
   a. cohesion
   b. hydrogen bonding
   c. adhesion
   d. hydrophilic vessel walls
   e. all of the above
4. Climates tend to be moderate near large bodies of water because
   a. a large amount of solar heat is absorbed during the gradual rise in temperature of the water.
   b. water releases heat to the environment as it cools.
   c. the high specific heat of water helps to moderate air temperatures.
   d. a great deal of heat is absorbed and released by the breaking and forming of hydrogen bonds.
   e. all of the above.
5. Temperature is a measure of
   a. specific heat.
   b. average kinetic energy of molecules.
   c. total kinetic energy of molecules.
   d. Celsius degrees.
   e. joules.

6. Evaporative cooling is a result of
   a. a low heat of vaporization.
   b. a high specific heat.
   c. absorption of heat as hydrogen bonds break.
   d. a reduction in the average kinetic energy of a liquid after energetic water molecules enter the gaseous state.
   e. release of heat caused by the breaking of hydrogen bonds when water molecules escape.

7. Ice floats because
   a. air is trapped in the crystalline lattice.
   b. the formation of hydrogen bonds releases heat; warmer objects float.
   c. it has a smaller surface area than liquid water.
   d. it insulates bodies of water so they do not freeze from the bottom up.
   e. hydrogen bonding spaces the molecules farther apart, creating a less dense structure.

8. The molarity of a solution is equal to
   a. Avogadro’s number of molecules in 1 liter of solvent.
   b. the number of moles of a solute in 1 liter of solution.
   c. the molecular mass of a solute in 1 liter of solution.
   d. the number of solute particles in 1 liter of solvent.
   e. 342 g if the solute is sucrose.

9. Some archaea are able to live in lakes with pH values of 11. How does pH 11 compare with the pH 7 typical of your body cells?
   a. It is four times more acidic than pH 7.
   b. It is four times more basic than pH 7.
   c. It is a thousand times more acidic than pH 7.
   d. It is a thousand times more basic than pH 7.
   e. It is ten thousand times more basic than pH 7.

10. A buffer
    a. changes pH by a magnitude of 10.
    b. releases excess OH⁻.
    c. releases excess H⁺.
    d. is often a weak acid-base pair.
    e. always maintains a neutral pH.

11. Which of the following is least soluble in water?
    a. polar molecules
    b. nonpolar molecules
    c. ionic compounds
    d. hydrophilic molecules
    e. anions

12. Which would be the best method for reducing acid precipitation?
    a. Raise the height of smokestacks so that exhaust enters the upper atmosphere.
    b. Add buffers and bases to bodies of water whose pH has dropped.
    c. Use coal-burning generators rather than nuclear power to produce electricity.
    d. Tighten emission control standards for factories and automobiles.
    e. Reduce the concentration of heavy metals in industrial exhaust.

13. What bonds must be broken for water to vaporize?
    a. polar covalent bonds
    b. nonpolar covalent bonds
    c. hydrogen bonds
    d. ionic bonds
    e. polar covalent and hydrogen bonds

14. How would you make a 0.1 M solution of glucose (C₆H₁₂O₆)? The mass numbers for these elements are approximately: C = 12, O = 16, H = 1.
    a. Mix 6 g C, 12 g H, and 6 g O in 1 liter of water.
    b. Mix 72 g C, 12 g H, and 96 g O in 1 liter of water.
    c. Mix 18 g of glucose with enough water to yield 1 liter of solution.
    d. Mix 29 g of glucose with enough water to yield 1 liter of solution.
    e. Mix 180 g of glucose with enough water to yield 1 liter of solution.

15. How many molecules of glucose would be in the 1 liter solution made in question 14?
    a. 0.1
    b. 6
    c. 60
    d. 6 x 10²³
    e. 6 x 10²²
16. Why is water such an excellent solvent?
   a. As a polar molecule, it can surround and dissolve ionic and polar molecules.
   b. It forms ionic bonds with ions, hydrogen bonds with polar molecules, and hydrophobic interactions with nonpolar molecules.
   c. It forms hydrogen bonds with itself.
   d. It has a high specific heat and a high heat of vaporization.
   e. It is wet and has a great deal of surface tension.

17. Which of the following when mixed with water would form a colloid?
   a. a large hydrophobic protein
   b. a large hydrophilic protein
   c. sugar
   d. cotton
   e. NaCl

18. Adding a base to a solution would
   a. raise the pH.
   b. lower the pH.
   c. decrease $[H^+]$.
   d. do both a and c.
   e. do both b and c.

19. A hydration shell is most likely to form around
   a. an ion.
   b. a fat.
   c. a sugar.
   d. both a and c.
   e. both b and c.

20. The following are the pH values for each item: cola--2; orange juice--3; beer--4; coffee--5; human blood--7.4. Which of these liquids has the highest molar concentration of $OH^-$?
   a. cola
   b. orange juice
   c. beer
   d. coffee
   e. human blood

21. Comparing the $[H^+]$ of orange juice and coffee, the $[H^+]$ of
   a. orange juice is 10 times higher.
   b. orange juice is 100 times higher.
   c. orange juice is 1,000 times higher.
   d. coffee is two times higher.
   e. coffee is 100 times higher.

22. The ability of water molecules to form hydrogen bonds accounts for water’s
   a. high specific heat.
   b. evaporative cooling.
   c. high heat of vaporization.
   d. cohesiveness and surface tension.
   e. All of the above result from water’s hydrogen-bonding capacity.
carb- = coal (carboxyl group: a functional group present in organic acids, consisting of a carbon atom double-bonded to an oxygen atom and a hydroxyl group)

sulf- = sulfur (sulphydryl group: a functional group that consists of a sulfur atom bonded to an atom of hydrogen)

thio- = sulfur (thiol: organic compounds containing sulphydryl groups)

Structure Your Knowledge

1. Construct a concept map that illustrates your understanding of the characteristics and significance of the three types of isomers. A suggested map is in the answer section. Comparing and discussing your map with that of a study partner would be most helpful.

2. Fill in the following table on the functional groups.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Molecular Formula</th>
<th>Names and Characteristics of Organic Compounds Containing Functional Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol</td>
<td>—OH</td>
<td>Aldehyde or ketone; polar group</td>
</tr>
<tr>
<td>Carboxyl</td>
<td>—COOH</td>
<td></td>
</tr>
<tr>
<td>Amine</td>
<td>—NH₂</td>
<td>Thiois; cross-links stabilize protein structure</td>
</tr>
<tr>
<td>Sulfhydryl</td>
<td>—SH</td>
<td></td>
</tr>
<tr>
<td>Phosphate</td>
<td>PO₄</td>
<td></td>
</tr>
</tbody>
</table>

Test Your Knowledge

MULTIPLE CHOICE: Choose the one best answer.

1. The tetravalence of carbon most directly results from
   a. its tetrahedral shape.
   b. its very slight electronegativity.
   c. its four electrons in the valence shell that can form four covalent bonds.
   d. its ability to form single, double, and triple bonds.
   e. its ability to form chains and rings of carbon atoms.

2. Hydrocarbons are not soluble in water because
   a. they are hydrophilic.
   b. the C—H bond is nonpolar.
   c. they do not ionize.
   d. they store energy in the many C—H bonds along the carbon backbone.
   e. they are lighter than water.

3. Which of the following is not true of an asymmetric carbon atom?
   a. It is attached to four different atoms or groups.
   b. It results in right- and left-handed versions of a molecule.
   c. It can be a part of enantiomers.
   d. Its configuration is in the shape of a tetrahedron.
   e. It can be a part of geometric isomers.

4. A reductionist approach to considering the structure and function of organic molecules would be based on
   a. mechanism.
   b. holism.
   c. determinism.
   d. vitalism.
   e. evolution.

5. The functional group that can cause an organic molecule to act as a base is
   a. —COOH.
   b. —OH.
   c. —SH.
   d. —OPO₄²⁻.
   e. —NH₂.

6. The functional group that confers acidic properties to organic molecules is
   a. —COOH.
   b. —H₂O.
   c. —SH.
   d. —C = O.

7. Which is not true about structural isomers?
   a. They have different chemical properties.
   b. They have the same molecular formula.
   c. Their atoms and bonds are arranged in different sequences.
   d. They are a result of restricted movement around a carbon double bond.
   e. Their possible numbers increase as carbon skeletons increase in size.

8. The fats stored in your body consist mostly of
   a. amino acids.
   b. alcohols.
   c. carboxylic acids.
   d. hydrocarbons.
   e. organic phosphates.
9. How many asymmetric carbons are there in the sugar ribose?

   a. 1  
   b. 2  
   c. 3  
   d. 4  
   e. 5

MATCHING: Match the formulas (a–f) to the terms at the right. Choices may be used more than once; more than one right choice may be available.

   a.  
   b.  
   c.  
   d.  
   e.  
   f.  

AC  1. structural isomers
BF  2. geometric isomers
ADE 3. can have enantiomers
E  4. carboxylic acid
E  5. can make cross-link in protein
ACDE 6. hydrophilic
BF  7. hydrocarbon
E  8. amino acid
AC  9. organic phosphate
AD 10. aldehyde
E  11. amine
C  12. ketone
The Theme of Emergent Properties
in the Chemistry of Life: A Review

At each stage in the hierarchy of levels from atoms through macromolecules, we have seen that novel properties arise with increasing structural organization.

**Word Roots**

**con-** = together (condensation reaction: a reaction in which two molecules become covalently bonded to each other through the loss of a small molecule, usually water)

di- = two (disaccharide: two monosaccharides joined together)
glyco- = sweet (glycogen: a polysaccharide sugar used to store energy in animals)
hydro- = water; -lyse = break (hydrolysis: breaking chemical bonds by adding water)
macro- = large (macromolecule: a large molecule)
meros- = part (polymer: a chain made from smaller organic molecules)
mono- = single; -sacchar = sugar (monosaccharide: simplest type of sugar)
poly- = many (polysaccharide: many monosaccharides joined together)
tri- = three (triacylglycerol: three fatty acids linked to one glycerol molecule)

**Structure Your Knowledge**

1. Describe the four structural levels in the conformation of a protein.
2. Identify the type of monomer or group shown by the formulas shown on the right. Then match the chemical formulae with their description. Answers may be used more than once.

   a. **Acid**

   b. **FA**

   c. **Purine**

   d. **Glycerol**

   e. **Phosphate**

   f. **Pentose Sugar**

   g. **Triose Sugar**

3. molecules that would combine to form a fat
4. molecule that would be attached to other monomers by a peptide bond
5. molecules or groups that would combine to form a nucleotide
6. monomer of a protein
7. groups that would be joined by phosphodiester bonds
8. most nonpolar (hydrophobic) molecule
Test Your Knowledge

MATCHING: Match the molecule with its type of molecule.

1. glycogen  A. carbohydrate
2. cholesterol  B. lipid
3. RNA  C. protein
4. collagen  D. nucleic acid
5. hemoglobin  
6. a gene  
7. triacylglycerol  
8. enzyme  
9. cellulose  
10. chitin

MULTIPLE CHOICE: Choose the one best answer.

1. Polymerization is a process that
   a. creates bonds between amino acids in the formation of a peptide chain.
   b. involves the removal of a water molecule.
   c. links the sugar of one nucleotide with the phosphate of the next.
   d. requires a condensation or dehydration reaction.
   e. may involve all of the above.

2. Which of the following is not true of a pentose?
   a. It can be found in nucleic acids.
   b. It can occur in a ring structure.
   c. It has the formula C₅H₁₀O₅.
   d. It has one carbonyl and four hydroxyl groups.
   e. It may be an aldose or a ketose.

3. Disaccharides can differ from each other in all of the following ways except
   a. in the number of their monosaccharides.
   b. as enantiomers.
   c. in the monomers involved.
   d. in the location of their glycosidic linkage.
   e. in their structural formulas.

4. Which of the following is not true of cellulose?
   a. It is the most abundant organic compound on Earth.
   b. It differs from starch because of the configuration of glucose and the geometry of the glycosidic linkage.
   c. It may be hydrogen-bonded to neighboring cellulose molecules to form microfibrils.
   d. Few organisms have enzymes that hydrolyze its glycosidic linkages.
   e. Its monomers are glucose with nitrogen-containing appendages.

5. Plants store most of their energy as
   a. unsaturated fats.
   b. glycogen.
   c. starch.
   d. sucrose.
   e. cellulose.

6. What happens when a protein denatures?
   a. It loses its primary structure.
   b. It loses its secondary and tertiary structures.
   c. It becomes irreversibly insoluble and precipitates.
   d. It hydrolyzes into component amino acids.
   e. Its hydrogen bonds, ionic bonds, hydrophobic interactions, disulfide bridges, and peptide bonds are disrupted.

7. The α helix of proteins is
   a. part of the tertiary structure and is stabilized by disulfide bridges.
   b. a double helix.
   c. stabilized by hydrogen bonds and commonly found in fibrous proteins.
   d. found in some regions of globular proteins and stabilized by hydrophobic interactions.
   e. a complementary sequence to messenger RNA.

8. A fatty acid that has the formula C₁₄H₂₆O₂ is
   a. saturated.
   b. unsaturated.
   c. branched.
   d. hydrophilic.
   e. part of a steroid molecule.

9. Three molecules of the fatty acid in question 8 are joined to a molecule of glycerol (C₃H₅O₃). The resulting molecule has the formula
   a. C₄₈H₉₈O₁₅
   b. C₄₆H₉₈O₁₇
   c. C₅₁H₁₀₂O₁₅
   d. C₅₁H₉₈O₁₇
   e. C₅₃H₁₀₄O₁₇
10. β pleated sheets are characterized by
   a. disulfide bridges between cysteine amino acids.
   b. parallel regions of the polypeptide chain held together by hydrophobic interactions.
   c. folds stabilized by hydrogen bonds between segments of the polypeptide backbone.
   d. membrane sheets composed of phospholipids.
   e. hydrogen bonds between adjacent cellulose molecules.

11. Cows can derive nutrients from cellulose because
   a. they can produce the enzymes that break the β linkages between glucose molecules.
   b. they chew and rechew their cud so that cellulose fibers are finally broken down.
   c. one of their stomachs contains bacteria that can hydrolyze the bonds of cellulose.
   d. their intestinal tract contains termites, which produce enzymes to hydrolyze cellulose.
   e. they can convert cellulose to starch and then hydrolyze starch to glucose.

12. Which of these molecules would provide the most energy (kcal/g) when eaten?
   a. glucose
   b. starch
   c. glycogen
   d. fat
   e. protein

13. What determines the sequence of the amino acids in a particular protein?
   a. its primary structure
   b. the sequence of nucleotides in RNA, which was determined by the sequence of nucleotides in the gene for that protein
   c. the sequence of nucleotides in DNA, which was determined by the sequence of nucleotides in RNA
   d. the sequence of RNA nucleotides making up the ribosome
   e. the three-dimensional shape of the protein

14. Sucrose is made from joining a glucose and a fructose molecule in a dehydration reaction. What is the molecular formula for this disaccharide?
   a. \( \text{C}_12\text{H}_{22}\text{O}_{11} \)
   b. \( \text{C}_6\text{H}_{12}\text{O}_6 \)
   c. \( \text{C}_10\text{H}_{20}\text{O}_{10} \)
   d. \( \text{C}_12\text{H}_{22}\text{O}_{11} \)
   e. \( \text{C}_12\text{H}_{24}\text{O}_{13} \)

15. How are the nucleotide monomers connected to form a polynucleotide?
   a. hydrogen bonds between complementary nitrogenous base pairs
   b. ionic attractions between phosphate groups
   c. disulfide bridges between cysteine amino acids
   d. covalent bonds between the sugar of one nucleotide and the phosphate of the next
   e. ester linkages between the carboxyl group of one nucleotide and the hydroxyl group on the ribose of the next

16. Which of the following would be the most hydrophobic molecule?
   a. cholesterol
   b. nucleotide
   c. amino acid
   d. chitin
   e. glucose

17. What is the best description of this molecule?

   ![Molecule Diagram]

   a. chitin
   b. amino acid
   c. polypeptide (tripeptide)
   d. nucleotide
   e. protein

18. Which number(s) in the molecule in question 17 refer(s) to a peptide bond?
   a. 1
   b. 2
   c. 3
   d. 4
   e. both 2 and 4

19. If the nucleotide sequence of one strand of a DNA helix is GCCTAA, what would be the sequence on the complementary strand?
   a. GCCTAA
   b. CGGAUU
   c. CGGATT
   d. ATTCGG
   e. TAAGCC
20. Monkeys and humans share many of the same DNA sequences and have similar proteins, indicating that
   a. the two groups belong to the same species.
   b. the two groups share a relatively recent common ancestor.
   c. humans evolved from monkeys.
   d. monkeys evolved from humans.
   e. the two groups first appeared on Earth at about the same time.

21. Which of the following would be the major component of the cell membrane of a fungus?
   a. cellulose
   b. chitin
   c. cholesterol
   d. phospholipids
   e. unsaturated fatty acids

22. Hydrophobic as well as hydrophilic interactions would be important for which of the following types of molecules?
   a. proteins
   b. unsaturated fats
   c. glycogen and cellulose
   d. nucleotides
   e. all of the above

23. What are trans fats?
   a. hydrogenated vegetable oils that have been identified with health risks
   b. fats made from cholesterol that are components of plaques in the walls of blood vessels
   c. fats that are derived from animal sources and are associated with cardiovascular disease
   d. fats that contain trans double bonds and may contribute to atherosclerosis
   e. polyunsaturated fats produced by removing H from fatty acids and forming cis double bonds

24. Which of the following is not a function performed by proteins?
   a. transport of oxygen in blood
   b. catalyst for metabolic reactions
   c. protection against disease
   d. signals and receptors
   e. primary component of cell membranes

**FILL IN THE BLANKS**

1. The man who determined the amino acid sequence of insulin was __________.
2. Cytosine always pairs with __________.
3. Adenine and guanine are __________.
4. A pentose joined to a nitrogenous base and a phosphate group is called a __________.
5. The conformation of a protein is determined by its __________ structure.
6. Proteins with more than one polypeptide chain have __________ structure.
7. The carbohydrate energy storage molecule of animals is __________.
8. Membranes are composed of a bilayer of __________.
9. The insoluble fiber listed on food packages consists primarily of __________.
10. Proteins that assist the proper folding of newly synthesized proteins are called __________.