Chapter 2

The Chemical Level of Organization

PowerPoint® Lecture Slides
prepared by Jason LaPres
Lone Star College - North Harris
2-1 Atoms are the basic particles of matter
Atoms

- **Matter** is made up of **atoms**
- Atoms join together to form chemicals with different characteristics
- Chemical characteristics determine physiology at the molecular and cellular levels
Atomic Structure

• Proton
  – Positive charge, 1 mass unit

• Neutron
  – Neutral, 1 mass unit

• Electron
  – Negative charge, low mass
A Diagram of Atomic Structure

Figure 2-1

Helium (He)
Atomic Structure

- Atomic Structure
  - Atomic number:
    - Number of protons
  - Mass number:
    - Number of protons plus neutrons
Atomic Structure

• Atomic Structure
  – Nucleus:
    • Contains protons and neutrons
  – Electron cloud:
    • Contains electrons
Hydrogen Atoms

(a) Electron cloud or space-filling model

(b) Electron-shell model

Figure 2-2
### TABLE 2-1 The Principal Elements in the Human Body

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen, O (65)</td>
<td>A component of water and other compounds; oxygen gas is essential for respiration</td>
</tr>
<tr>
<td>Carbon, C (18.6)</td>
<td>Found in all organic molecules</td>
</tr>
<tr>
<td>Hydrogen, H (9.7)</td>
<td>A component of water and most other compounds in the body</td>
</tr>
<tr>
<td>ELEMENT (/% OF BODY WEIGHT)</td>
<td>SIGNIFICANCE</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Nitrogen, N (3.2)</td>
<td>Found in proteins, nucleic acids, and other organic compounds</td>
</tr>
<tr>
<td>Calcium, Ca (1.8)</td>
<td>Found in bones and teeth; important for membrane function, nerve impulses, muscle contraction, and blood clotting</td>
</tr>
<tr>
<td>Phosphorus, P (1)</td>
<td>Found in bones and teeth, nucleic acids, and high-energy compounds</td>
</tr>
</tbody>
</table>
## TABLE 2-1 The Principal Elements in the Human Body

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium, K (0.4)</td>
<td>Important for proper membrane function, nerve impulses, and muscle contraction</td>
</tr>
<tr>
<td>Sodium, Na (0.2)</td>
<td>Important for membrane function, nerve impulses, and muscle contraction</td>
</tr>
<tr>
<td>Chlorine, Cl (0.2)</td>
<td>Important for membrane function and water absorption</td>
</tr>
<tr>
<td>ELEMENT</td>
<td>SIGNIFICANCE</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>Magnesium, Mg (0.06)</td>
<td>Required for activation of several enzymes</td>
</tr>
<tr>
<td>Sulfur, S (0.04)</td>
<td>Found in many proteins</td>
</tr>
<tr>
<td>Iron, Fe (0.007)</td>
<td>Essential for oxygen transport and energy capture</td>
</tr>
<tr>
<td>Iodine, I (0.0002)</td>
<td>A component of hormones of the thyroid gland</td>
</tr>
</tbody>
</table>
Isotopes

- **Elements** are determined by the atomic number of an atom
  - Remember atomic number = number of protons
  - Elements are the most basic chemicals
- **Isotopes** are the specific version of an element based on its mass number
  - Remember that mass number = number of protons plus the number of neutrons
  - Only neutrons are different because the number of protons determines the element
Atomic Weight

• Exact mass of all particles
  – Measured in Daltons

• Average of the mass numbers of the isotopes
Electron Shells

• Electrons and Energy Levels
  – Electrons in the electron cloud determine the **reactivity** of an atom
  – The electron cloud contains **shells**, or energy levels that hold a maximum number of electrons:
    • Lower shells fill first
    • Outermost shell is the **valence shell**, and it determines bonding
    • The number of electrons per shell corresponds to the number of atoms in that row of the **periodic table**
The Electron Shells of Two Atoms

Figure 2-3

(a) Carbon atom
(6p⁺, 6n⁰, 6e⁻)

(b) Neon atom
(10p⁺, 10n⁰, 10e⁻)
2-2 Chemical bonds are forces formed by atom interactions
Chemical Bonds

• Chemical bonds form molecules and/or compounds
  – Molecules:
    • Two or more atoms joined by strong bonds
  – Compounds:
    • Two or more atoms OF DIFFERENT ELEMENTS joined by strong or weak bonds
  – Compounds are all molecules, but not all molecules are compounds:
    • $\text{H}_2 = \text{molecule only}$       $\text{H}_2\text{O} = \text{molecule and compound}$
Ionic Bonds

• One atom — the electron donor — loses one or more electrons and becomes a cation, with a positive charge

• Another atom — the electron acceptor — gains those same electrons and becomes an anion, with a negative charge

• Attraction between the opposite charges then draws the two ions together
Ionic Bonding

**Figure 2-4a**

(a) Formation of an ionic bond
Ionic Bonding

Figure 2-4b

Sodium chloride crystal

Chloride ions (Cl⁻)
Sodium ions (Na⁺)
<table>
<thead>
<tr>
<th>CATIONS</th>
<th>ANIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺ (sodium)</td>
<td>Cl⁻ (chloride)</td>
</tr>
<tr>
<td>K⁺ (potassium)</td>
<td>HCO₃⁻ (bicarbonate)</td>
</tr>
<tr>
<td>Ca²⁺ (calcium)</td>
<td>HPO₄²⁻ (biphosphate)</td>
</tr>
<tr>
<td>Mg²⁺ (magnesium)</td>
<td>SO₄²⁻ (sulfate)</td>
</tr>
</tbody>
</table>
Covalent Bonds

• Involve the sharing of pairs of electrons between atoms
  – One electron is donated by each atom to make the pair of electrons
  – Sharing one pair of electrons is a single covalent bond
  – Sharing two pairs of electrons is a double covalent bond
  – Sharing three pairs of electrons is a triple covalent bond
# Covalent Bonds

<table>
<thead>
<tr>
<th></th>
<th>ELECTRON-SHELL MODEL AND STRUCTURAL FORMULA</th>
<th>SPACE-FILLING MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td><img src="image1" alt="H-H" /></td>
<td><img src="image2" alt="H-H" /></td>
</tr>
<tr>
<td>Hydrogen (H₂)</td>
<td><strong>H-H</strong></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td><img src="image3" alt="O=O" /></td>
<td><img src="image4" alt="O=O" /></td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td><strong>O=O</strong></td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td><img src="image5" alt="O=C=O" /></td>
<td><img src="image6" alt="O=C=O" /></td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td><strong>O=C=O</strong></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2-5

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Chemical Bonds

• Covalent Bonds
  – Nonpolar covalent bonds
    • Involve *equal* sharing of electrons because atoms involved in the bond have equal pull for the electrons
  – Polar covalent bonds
    • Involve the *unequal* sharing of electrons because one of the atoms involved in the bond has a disproportionately strong pull on the electrons
    • Form *polar molecules* — like water
Hydrogen Bonds

• Bonds between adjacent molecules, not atoms

• Involve slightly positive and slightly negative portions of polar molecules being attracted to one another

• Hydrogen bonds between H$_2$O molecules cause surface tension
Hydrogen Bonds

Figure 2-6

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2-3 Decomposition, synthesis, and exchange reactions are important chemical reactions in physiology.
Basic Energy Concepts

• **Energy**
  – The power to do work

• **Work**
  – A change in mass or distance

• **Kinetic Energy**
  – Energy of motion

• **Potential Energy**
  – Stored energy

• **Chemical Energy**
  – Potential energy stored in chemical bonds
Types of Reactions

• **Decomposition Reaction** (Catabolism)
  - Breaks chemical bonds
  - $AB \rightarrow A + B$
  - Hydrolysis: $ABCDE + H_2O \rightarrow ABC-H + HO-DE$

• **Synthesis Reaction** (Anabolism)
  - Forms chemical bonds
  - $A + B \rightarrow AB$
  - Dehydration synthesis (condensation)
    $$ABC-H + HO-DE \rightarrow ABCDE + H_2O$$
Types of Reactions

• Exchange Reaction
  – Involves decomposition first, then synthesis
  – \( AB + CD \rightarrow AD + CB \)
Reversible Reactions

• A reaction that occurs simultaneously in both directions
• $AB \leftrightarrow A + B$
• At equilibrium the amounts of chemicals do not change even though the reactions are still occurring
  – Reversible reactions seek equilibrium, balancing opposing reaction rates
  – Add or remove reactants:
    • Reaction rates adjust to reach a new equilibrium
### Table 2-3 Rules of Chemical Notation

1. The abbreviation of an element indicates one atom of that element:
   
   \[ \text{H} = \text{an atom of hydrogen}; \quad \text{O} = \text{an atom of oxygen} \]

2. A number preceding the abbreviation of an element indicates more than one atom:
   
   \[ 2\text{H} = \text{two individual atoms of hydrogen} \]
   \[ 2\text{O} = \text{two individual atoms of oxygen} \]

3. A subscript following the abbreviation of an element indicates a molecule with that number of atoms:
   
   \[ \text{H}_2 = \text{a hydrogen molecule composed of two hydrogen atoms} \]
   \[ \text{O}_2 = \text{an oxygen molecule composed of two oxygen atoms} \]

4. In a description of a chemical reaction, the interacting participants are called **reactants**, and the reaction generates one or more **products**. An arrow indicates the direction of the reaction, from reactants (usually on the left) to products (usually on the right). In the following reaction, two atoms of hydrogen combine with one atom of oxygen to produce a single molecule of water.
   
   \[ 2\text{H} + \text{O} \rightarrow \text{H}_2\text{O} \]
### TABLE 2-3  Rules of Chemical Notation

5. A superscript plus or minus sign following the abbreviation for an element indicates an ion. A single plus sign indicates an ion with a charge of +1 (loss of one electron). A single minus sign indicates an ion with a charge of −1 (gain of one electron). If more than one electron has been lost or gained, the charge on the ion is indicated by a number preceding the plus or minus.

- \( \text{Na}^+ = \) one sodium ion (has lost 1 electron)
- \( \text{Cl}^- = \) one chloride ion (has gained 1 electron)
- \( \text{Ca}^{2+} = \) one calcium ion (has lost 2 electrons)

6. Chemical reactions neither create nor destroy atoms—they merely rearrange them into new combinations. Therefore, the numbers of atoms of each element must always be the same on both sides of the equation. When this is the case, the equation is balanced.

Unbalanced: \( \text{H}_2 + \text{O}_2 \longrightarrow \text{H}_2\text{O} \)

Balanced: \( 2\text{H}_2 + \text{O}_2 \longrightarrow 2\text{H}_2\text{O} \)
2-4 Enzymes catalyze specific biochemical reactions by lowering a reaction’s activation energy
Enzymes

• Chemical reactions in cells cannot start without help
  – **Activation energy** is the amount of energy needed to get a reaction started
  – **Enzymes** are protein **catalysts** that lower the activation energy of reactions
The Effect of Enzymes on Activation Energy

Figure 2-7

Enzymes
2-5 Inorganic compounds usually lack carbon, and organic compounds always contain carbon
Inorganic Versus Organic Compounds

• **Nutrients**
  – Essential molecules obtained from food

• **Metabolites**
  – Molecules made or broken down in the body

• **Inorganic**
  – Molecules not based on carbon and hydrogen
  – Carbon dioxide, oxygen, water, and inorganic acids, bases, and salts

• **Organic**
  – Molecules based on carbon and hydrogen
  – Carbohydrates, proteins, lipids, nucleic acids
Physiological systems depend on water
Importance of Water

- Water accounts for up to two-thirds of your total body weight
- Water is an essential reactant in the chemical reactions of living systems
- Water has a very high heat capacity
- Water is an excellent solvent
Importance of Water

• The Properties of Aqueous Solutions
  – Ions and polar compounds undergo ionization or dissociation in water
  – Electrolytes are inorganic ions that conduct electricity in solution
The Role of Water Molecules in Solutions

(a) Water molecule

(b) Sodium chloride in solution

Figure 2-8
2-7 Body fluid pH is vital for homeostasis
pH and Homeostasis

• **pH**
  – The concentration of hydrogen ions (H⁺) in a solution

• **Neutral pH**
  – A balance of H⁺ and OH⁻
  – Pure water = 7.0

• **pH of Human Blood**
  – Ranges from 7.35 to 7.45
pH and Homeostasis

• **Acidic**: pH lower than 7.0
  – High H⁺ concentration
  – Low OH⁻ concentration

• **Basic** (or *alkaline*): pH higher than 7.0
  – Low H⁺ concentration
  – High OH⁻ concentration
pH and Homeostasis

• pH Scale
  – Has an *inverse* relationship with H⁺ concentration:
    • More H⁺ ions mean *lower* pH, less H⁺ ions mean *higher* pH
Figure 2-9

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2-8 Acids, bases, and salts are inorganic compounds with important physiological roles.
Acids, Bases, and Salts

• **Acid**
  – A solute that adds hydrogen ions to a solution
  – Proton donor
  – Strong acids dissociate completely in solution

• **Base**
  – A solute that removes hydrogen ions from a solution
  – Proton acceptor
  – Strong bases dissociate completely in solution

• **Weak Acids and Weak Bases**
  – Fail to dissociate completely
  – Help to balance the pH
Salts

• Solutes that dissociate into cations and anions other than hydrogen ions and hydroxide ions
Buffers and pH

• Buffers
  – Weak acid/salt compounds
  – Neutralizes either strong acid or strong base
  – Sodium bicarbonate is very important in humans

• Antacids
  – A basic compound that neutralizes acid and forms a salt
  – Tums, Rolaids, etc.
2-9 Carbohydrates contain carbon, hydrogen, and oxygen in a 1:2:1 ratio
Carbohydrates

- Carbohydrates contain carbon, hydrogen, and oxygen in a 1:2:1 ratio
  - **Monosaccharides:**
    - Simple sugars with three to seven carbon atoms
    - Glucose, fructose, galactose
  - **Disaccharides:**
    - Two simple sugars condensed by dehydration synthesis
    - Sucrose, maltose
  - **Polysaccharides:**
    - Many monosaccharides condensed by dehydration synthesis
    - Glycogen, starch, cellulose
Glucose

(a)

(b)

(c)

Figure 2-10
Dehydration Synthesis

Figure 2-11a

Sucrose

Glucose + Fructose → Sucrose + H₂O
Figure 2-11b

Hydrolysis of Sucrose to Glucose and Fructose.
Glycogen

Figure 2-11c
<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>EXAMPLES</th>
<th>PRIMARY FUNCTIONS</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monosaccharides</strong></td>
<td>Glucose, fructose</td>
<td>Energy source</td>
<td>Manufactured in the body and obtained from food; found in body fluids</td>
</tr>
<tr>
<td>(Simple Sugars)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Disaccharides</strong></td>
<td>Sucrose, lactose, maltose</td>
<td>Energy source</td>
<td>Sucrose is table sugar, lactose is present in milk; all must be broken down to monosaccharides before absorption</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Polysaccharides</strong></td>
<td>Glycogen</td>
<td>Storage of glucose molecules</td>
<td>Glycogen is in animal cells; other polysaccharides (starches and cellulose) are in plant cells</td>
</tr>
</tbody>
</table>
2-10 Lipids contain a carbon-to-hydrogen ratio of 1:2
Lipids

• Mainly hydrophobic molecules such as fats, oils, and waxes
• Made mostly of carbon and hydrogen atoms
• Include
  – Fatty acids
  – Fats
  – Steroids
  – Phospholipids
Fatty Acids

• Long chains of carbon and hydrogen with a *carboxylic acid group* (COOH) at one end

• Are relatively nonpolar, *except* the carboxylic group

• Fatty acids may be
  – **Saturated** with hydrogen (no covalent bonds)
  – **Unsaturated** (one or more double bonds):
    • Monounsaturated = one double bond
    • Polyunsaturated = two or more double bonds
Fatty Acids

Figure 2-12a

(a) Lauric acid (C_{12}H_{24}O_{2})
Lipids

Figure 2-12b
Fats

• Fatty acids attached to a glycerol molecule

• **Triglycerides** are the three fatty-acid tails
  – Also called triacylglycerols or neutral fats
  – Have three important functions:
    • Energy source
    • Insulation
    • Protection
Triglyceride Formation

Figure 2-13
Steroids

• Four rings of carbon and hydrogen with an assortment of functional groups

• Types of steroids
  – Cholesterol
  – Estrogens and testosterone
  – Corticosteroids and calcitriol
  – Bile salts
A Cholesterol Molecule

Figure 2-14
Phospholipids

• **Diglycerides** attached to a phosphate group (phospholipid)

• Have hydrophilic heads and hydrophobic tails and are structural lipids, components of plasma (cell) membranes
A Phospholipid Molecule

Figure 2-15
<table>
<thead>
<tr>
<th>LIPID TYPE</th>
<th>EXAMPLES</th>
<th>PRIMARY FUNCTIONS</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatty Acids</td>
<td>Lauric acid</td>
<td>Energy sources</td>
<td>Absorbed from food or synthesized in cells; transported in the blood for use in many tissues</td>
</tr>
<tr>
<td>Fats</td>
<td>Monoglycerides, diglycerides, triglycerides</td>
<td>Energy source, energy storage, insulation, and physical protection</td>
<td>Stored in fat deposits; must be broken down to fatty acids and glycerol before they can be used as an energy source</td>
</tr>
<tr>
<td>Steroids</td>
<td>Cholesterol</td>
<td>Structural component of cell membranes, hormones, digestive secretions in bile</td>
<td>All have the same carbon-ring framework</td>
</tr>
<tr>
<td>Phospholipids</td>
<td>Lecithin</td>
<td>Structural components of cell membranes</td>
<td>Composed of fatty acids and nonlipid molecules</td>
</tr>
</tbody>
</table>
2-11 Proteins are formed from amino acids and contain carbon, hydrogen, oxygen, and nitrogen
Proteins

- **Proteins** are the most abundant and important organic molecules
- Contain basic elements
  - Carbon (C), hydrogen (H), oxygen (O), and nitrogen (N)
- Basic building blocks
  - 20 amino acids
Protein Functions

- **Support**
  - Structural proteins

- **Movement**
  - Contractile proteins

- **Transport**
  - Transport (carrier) proteins

- **Buffering**
  - Regulation of pH

- **Metabolic regulation**
  - Enzymes

- **Coordination and control**
  - Hormones

- **Defense**
  - Antibodies
Protein Structure

• Long chains of amino acids

• Amino acid structure
  – Central carbon atom
  – Hydrogen atom
  – Amino group (—NH₂)
  – Carboxylic acid group (—COOH)
  – Variable side chain or R group
Amino Acids and the Formation of Peptide Bonds

Figure 2-16a

(a) Structure of an amino acid
Amino Acids and the Formation of Peptide Bonds

Figure 2-16b

(b) Peptide bond formation
Proteins

• **Protein Shape**
  – **Primary structure:**
    • The sequence of amino acids along a polypeptide
  – **Secondary structure:**
    • Hydrogen bonds form spirals or pleats
  – **Tertiary structure:**
    • Secondary structure folds into a unique shape
  – **Quaternary structure:**
    • Final protein shape:
      – several tertiary structures together
Protein Structure

Figure 2-17 a,b
Protein Structure

(c) Hemoglobin

(d) Keratin fiber

Figure 2-17 c,d
Protein Structure

• Denaturation
  – Loss of shape and function due to heat or pH
Enzyme Function

• Enzymes are catalysts
  – Proteins that lower the activation energy of a chemical reaction
  – Are not changed or used up in the reaction
  – Enzymes are also:
    • Specific — will only work on limited types of substrates
    • Limited — by their saturation
    • Regulated — by other cellular chemicals
A Simplified View of Enzyme Structure and Function

**Figure 2-18**

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2-12 DNA and RNA are nucleic acids
Nucleic Acids

• Nucleic acids are large organic molecules found in the nucleus which *store and process information* at the molecular level
  – Deoxyribonucleic acid (DNA):
    • Determines inherited characteristics
    • Directs protein synthesis
    • Controls enzyme production
    • Controls metabolism
  – Ribonucleic acid (RNA):
    • Controls intermediate steps in protein synthesis
Structure of Nucleic Acids

- DNA and RNA are strings of nucleotides

- Nucleotides
  - Are the building blocks of DNA and RNA
  - Have three molecular parts:
    - A sugar (deoxyribose or ribose)
    - Phosphate group
    - Nitrogenous base (A, G, T, C, or U)
Figure 2-19a

The Structure of Nucleic Acids
Figure 2-19b

(b) Nitrogenous bases in nucleic acids

- **A** Adenine
- **G** Guanine
- **C** Cytosine
- **T** Thymine (DNA only)
- **U** Uracil (RNA only)
The Structure of Nucleic Acids

Figure 2-19c

(c) RNA molecule
Figure 2-19d
<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>RNA</th>
<th>DNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>Ribose</td>
<td>Deoxyribose</td>
</tr>
<tr>
<td>Nitrogenous Bases</td>
<td>Adenine, Guanine, Cytosine, Uracil</td>
<td>Adenine, Guanine, Cytosine, Thymine</td>
</tr>
<tr>
<td>Number of Nucleotides in a Typical Molecule</td>
<td>Varies from fewer than 100 nucleotides to about 50,000</td>
<td>Always more than 45 million nucleotides</td>
</tr>
<tr>
<td>Shape of Molecule</td>
<td>Single strand</td>
<td>Paired strands coiled in a double helix</td>
</tr>
<tr>
<td>Function</td>
<td>Performs protein synthesis as directed by DNA</td>
<td>Stores genetic information that controls protein synthesis</td>
</tr>
</tbody>
</table>
2-13 ATP is a high-energy compound used by cells
ATP

• Nucleotides can be used to store energy
  – Adenosine diphosphate (ADP):
    • Two phosphate groups; di- = 2
  – Adenosine triphosphate (ATP):
    • Three phosphate groups; tri- = 3

• Adding a phosphate group to ADP with a high-energy bond to form the high-energy compound ATP

• ATPase
  – The enzyme that catalyzes phosphorylation (the addition of a high-energy phosphate group to a molecule)
The Structure of ATP

Figure 2-20
Energy Flow and the Recycling of ATP within Cells

Figure 2-21
2-14 Chemicals form functional units called cells
Chemicals Form Cells

- Biochemical building blocks form functional units called cells
- Your body recycles and renews all of its chemical components at intervals ranging from minutes to years
An Overview of the Structures of Organic Compounds in the Body

**Figure 2-22**

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<table>
<thead>
<tr>
<th>CLASS</th>
<th>BUILDING BLOCKS</th>
<th>SOURCES</th>
<th>FUNCTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INORGANIC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Hydrogen and oxygen atoms</td>
<td>Absorbed as liquid water or generated by metabolism</td>
<td>Solvent; transport medium for dissolved materials and heat; cooling through evaporation; medium for chemical reactions; reactant in hydrolysis</td>
</tr>
<tr>
<td>Acids, bases, salts</td>
<td>$H^+$, $OH^-$, various anions and cations</td>
<td>Obtained from the diet or generated by metabolism</td>
<td>Structural components; buffers; sources of ions</td>
</tr>
<tr>
<td>Dissolved gases</td>
<td>Oxygen, carbon, nitrogen, and other atoms</td>
<td>Atmosphere</td>
<td>$O_2$: required for normal cellular metabolism</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$CO_2$: generated by cells as a waste product</td>
</tr>
<tr>
<td><strong>ORGANIC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>C, H, and O; CHO in a 1:2:1 ratio</td>
<td>Obtained from the diet or manufactured in the body</td>
<td>Energy source; some structural role when attached to lipids or proteins; energy storage</td>
</tr>
<tr>
<td>Lipids</td>
<td>C, H, O, sometimes N or P; CHO not in 1:2:1 ratio</td>
<td>Obtained from the diet or manufactured in the body</td>
<td>Energy source; energy storage; insulation; structural components; chemical messengers; protection</td>
</tr>
<tr>
<td>Proteins</td>
<td>C, H, O, N, often S</td>
<td>20 common amino acids; roughly half can be manufactured in the body, others must be obtained from the diet</td>
<td>Catalysts for metabolic reactions; structural components; movement; transport; buffers; defense; control and coordination of activities</td>
</tr>
<tr>
<td>Nucleic acids</td>
<td>C, H, O, N, and P; nucleotides composed of phosphates, sugars, and nitrogenous bases</td>
<td>Obtained from the diet or manufactured in the body</td>
<td>Storage and processing of genetic information</td>
</tr>
<tr>
<td>High-energy compounds</td>
<td>Nucleotides joined to phosphates by high-energy bonds</td>
<td>Synthesized by all cells</td>
<td>Storage or transfer of energy</td>
</tr>
</tbody>
</table>

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