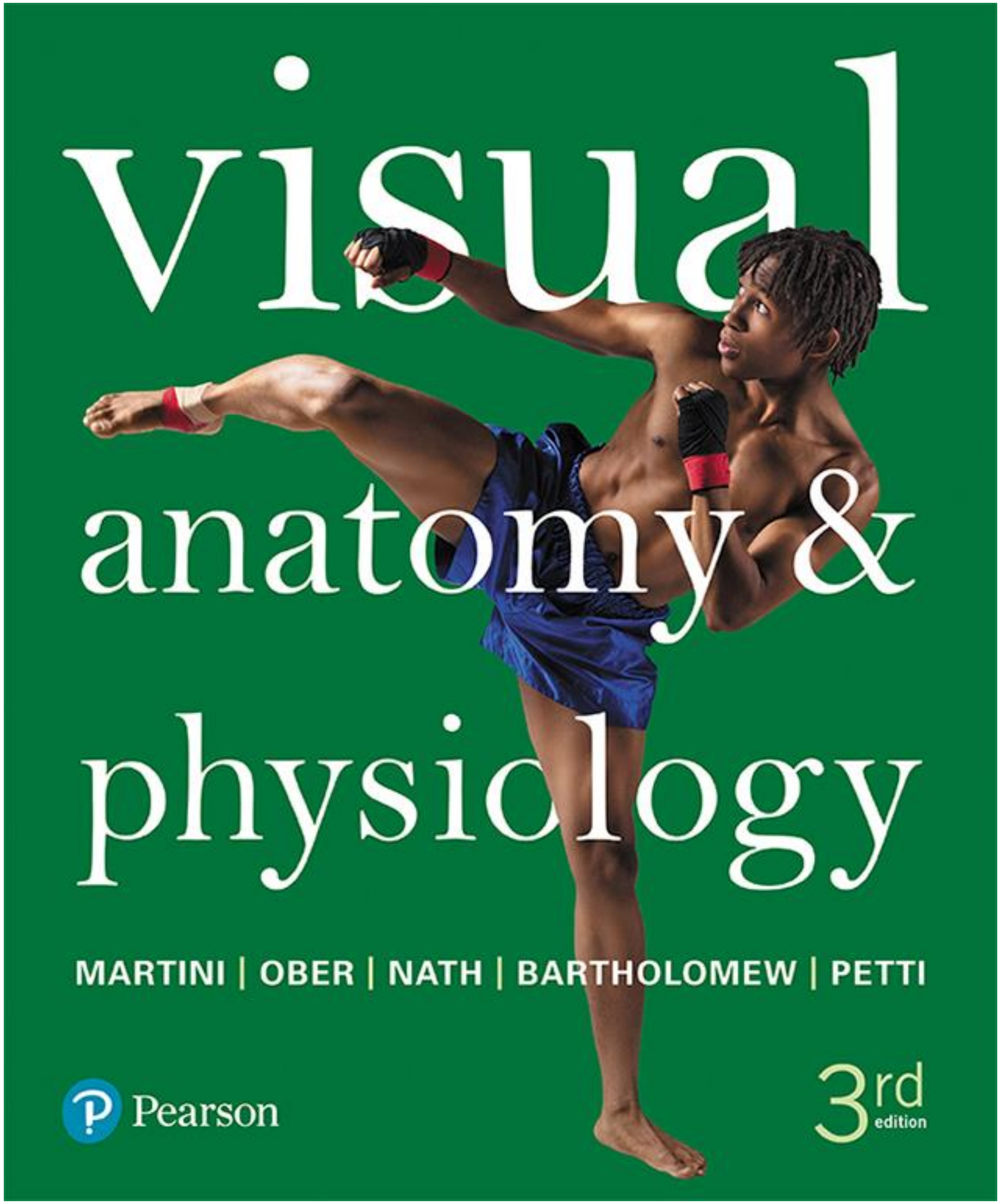


2

Chemical Level of Organization

Lecture Presentation by
Lori Garrett

Section 1: Atoms, Molecules, and Compounds

Learning Outcomes

2.1 Define an atom, and describe the properties of its subatomic particles.

2.2 Describe an atom and how atomic structure affects the mass number and atomic weight of the various chemical elements.

2.3 Explain the relationship between electrons and energy levels.

2.4 Compare the ways in which atoms combine to form molecules and compounds.

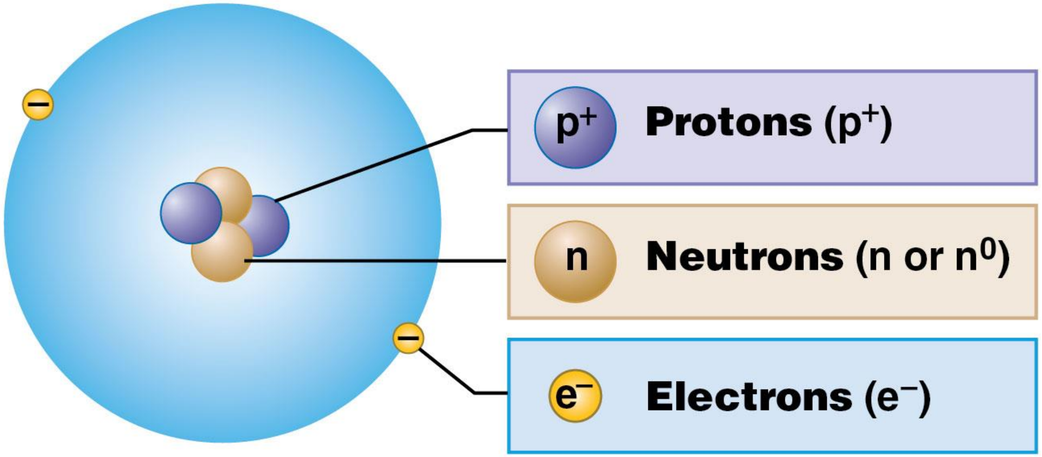
2.5 Describe the three states of matter and the importance of hydrogen bonds in liquid water.

Module 2.1: Atoms are the basic particles of matter

Chemical level of organization

- First level of studying the human body is chemical level of organization
- Chemistry studies the structure of matter
  - **Matter**
    - Anything that takes up space and has mass
  - **Mass**
    - The quantity of material in matter
    - On Earth, mass is equivalent to weight

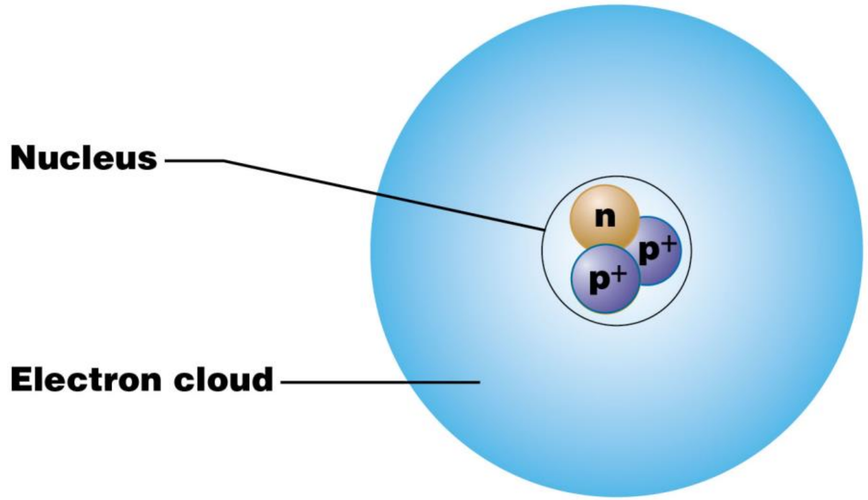
Module 2.1: Atoms



Atoms—smallest stable units of matter

- Composed of **subatomic particles**
  - **Protons** (p^+)
    – Have a positive electrical charge
  - **Neutrons** (n or $n^{0)}$
    – Are electrically neutral (uncharged)
  - **Electrons** (e^-)
    – Have a negative electrical charge
    – Are much smaller than protons or neutrons (about 1/1836 the mass)

Module 2.1: Atoms

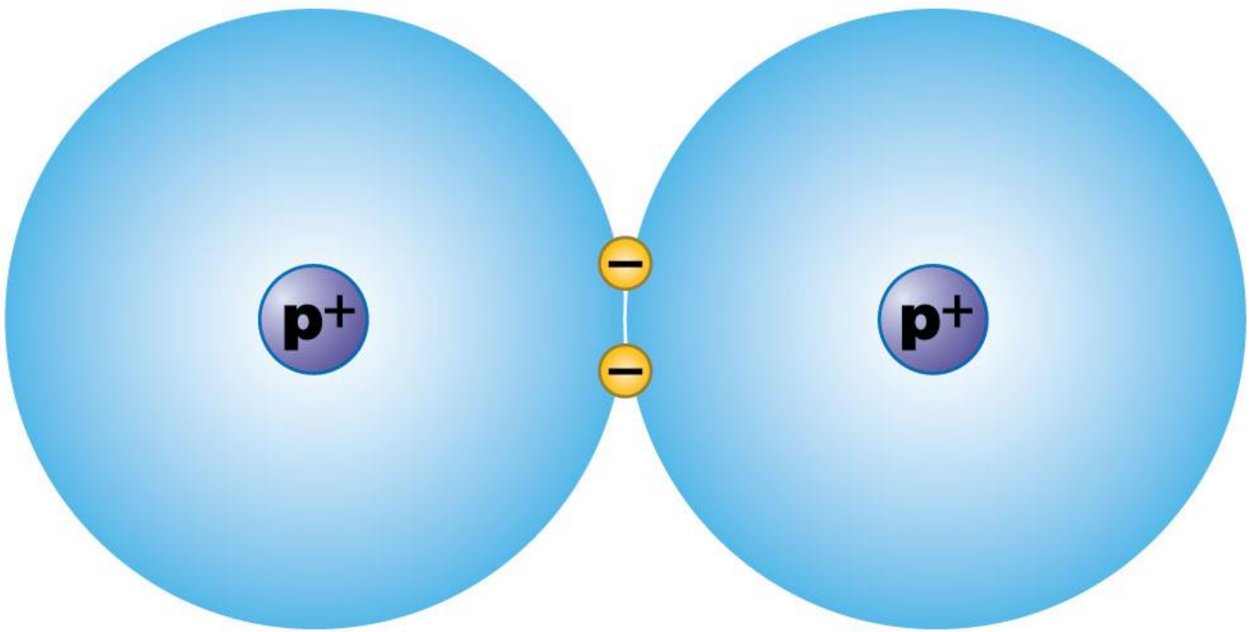


An atom can be subdivided into:

- **Nucleus**
  - At the center of an atom
  - Contains one or more protons
  - May also contain neutrons
  - Mass of atom mainly determined by number of protons and neutrons
- **Electron cloud**
  - Created by whirl of electrons around the nucleus

Module 2.1: Atoms

Atoms interact by means of their electrons to produce larger, more complex structures.



Module 2.1: Review

A. What is the relationship between an atom and matter?
B. Which subatomic particles have a positive charge? Which are uncharged?
C. Describe the subatomic particle not in the nucleus.
D. The gravitational field of the moon is 17% of Earth's. How would the weight and mass of a 100-pound astronaut change on the moon?

Learning Outcome: Define atom, and describe the properties of its subatomic particles.

Module 2.2: Typical atoms contain protons, neutrons, and electrons

Atoms and elements

- Atoms normally contain equal numbers of protons and electrons

Atomic number

- Total number of protons in an atom

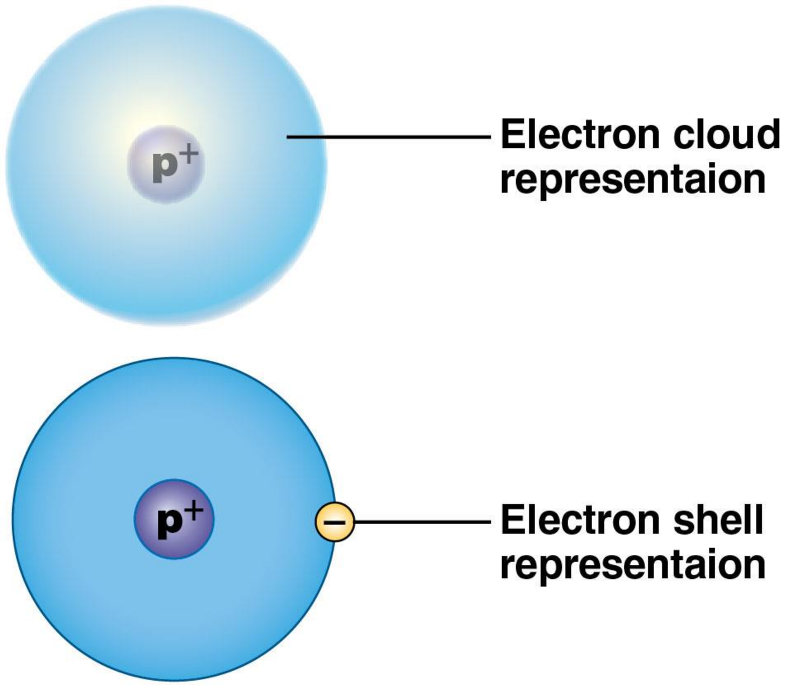
Mass number

- Total number of protons and neutrons in an atom

Element

- Substance composed only of atoms with same atomic number
- *Example:* **hydrogen**

Module 2.2: Atoms contain protons, neutrons, and electrons



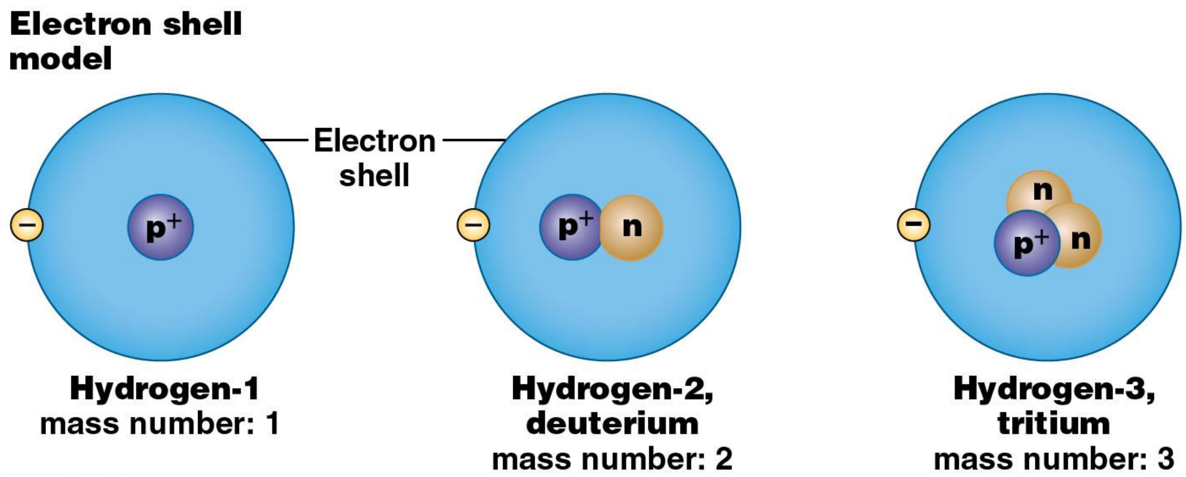
Hydrogen (H)

- Simplest atom
- Atomic number of 1
- Contains 1 proton and 1 electron
- Proton in the center of the atom (the nucleus)
- Electron whirls around the nucleus in the **electron cloud**
- Electrons are often shown in fixed orbit
  - In 2-dimensional structure, electrons occupy an **electron shell**.

Module 2.2: Atoms contain protons, neutrons, and electrons

Isotopes

- Atoms with same number of protons but different numbers of neutrons
- Identical chemical properties
- Different **mass number** (tells number of subatomic particles in nuclei)



Module 2.2: Atoms contain protons, neutrons, and electrons

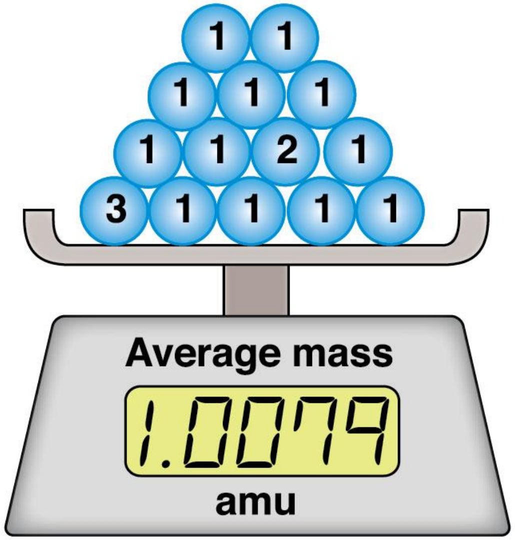
Atomic mass

- Actual mass of an atom of a specific isotope
- Measured in **atomic mass units** (**amu**) or daltons
  - One amu = 1/12 mass of a carbon-12 atom
  - Very close to the weight of one proton or one neutron

Module 2.2: Atoms contain protons, neutrons, and electrons

Atomic weight

- Equals average mass of an element, including different isotopes in proportion
- Very close to mass number of most common isotope
- *Example:*
  - Hydrogen atomic number = 1 (one proton)
  - Hydrogen atomic weight = 1.0079
    - Not all hydrogen atoms have 0 neutrons
    - 0.015 percent have 1 neutron (mass number 2)
    - Lower percentage have 2 neutrons (mass number 3)



Atomic weight of hydrogen = 1.0079

Module 2.2: Atoms contain protons, neutrons, and electrons

Elements

- Principal elements
  - Thirteen most abundant elements by body weight
- **Trace elements**
  - Fourteen other elements present in the body in very small amounts
- All elements represented by a **chemical symbol** based on:
  - English names (e.g., O for oxygen; C for carbon)
  - Other language names (e.g., Na for sodium from Latin *natrium*)

Principal Elements of the Human Body

Element (% of total body weight)	Significance
Oxygen, O (65)	A component of water and other compounds (substances composed of two or more different elements); as a gas, essential for respiration
Carbon, C (18.6)	Found in all organic compounds
Hydrogen, H (9.7)	A component of water and most other compounds in the body
Nitrogen, N (3.2)	Found in proteins, nucleic acids, and other organic compounds

Principal Elements of the Human Body

Element (% of total body weight)	Significance
Calcium, Ca (1.8)	Found in bones and teeth; important for plasma membrane function, nerve impulses, muscle contraction, and blood clotting
Phosphorus, P (1.0)	Found in bones and teeth, nucleic acids, and high-energy compounds
Potassium, K (0.4)	Important for plasma membrane function, nerve impulses, and muscle contraction
Sodium, Na (0.2)	Important for blood volume, plasma membrane function, nerve impulses, and muscle contraction

Principal Elements of the Human Body

Element (% of total body weight)	Significance
Chlorine, C (0.2)	Important for blood volume, plasma membrane function, and water absorption
Magnesium, Mg (0.06)	A cofactor* for many enzymes
Sulfur, S (0.04)	Found in many proteins
Iron, Fe (0.007)	Essential for oxygen transport and energy capture

Principal Elements of the Human Body

Element (% of total body weight)	Significance
Iodine, I (0.0002)	A component of hormones of the thyroid gland
Trace elements: silicon (Si), fluorine (F), copper (Cu), manganese (Mn), zinc (Zn), selenium (Se), cobalt (Co), molybdenum (Mo), cadmium (Cd), chromium (Cr), tin (Sn), aluminum (Al), boron (B), and vanadium (V)	Some function as cofactors*; the functions of many trace elements are poorly understood

* A cofactor is a mineral or nonprotein compound. It acts with proteins called enzymes to speed up chemical reactions in living things.

Module 2.2: Review

A. Which is larger: an element's atomic number or mass number?

B. Carbon-12 (^{12}C) is the most common form of the element carbon. How is the isotope carbon-13 (^{13}C) similar to and different from ^{12}C?

C. How is it possible for two samples of hydrogen to contain the same number of atoms yet have different weights?

D. Describe trace elements.

E. List the chemical symbols of the six most abundant elements in the human body and their total percentage contribution to total body weight.

Learning Outcome: Describe an atom and how atomic structure affects the mass number and atomic weight of the various chemical elements.

Module 2.3: Electrons occupy various energy levels

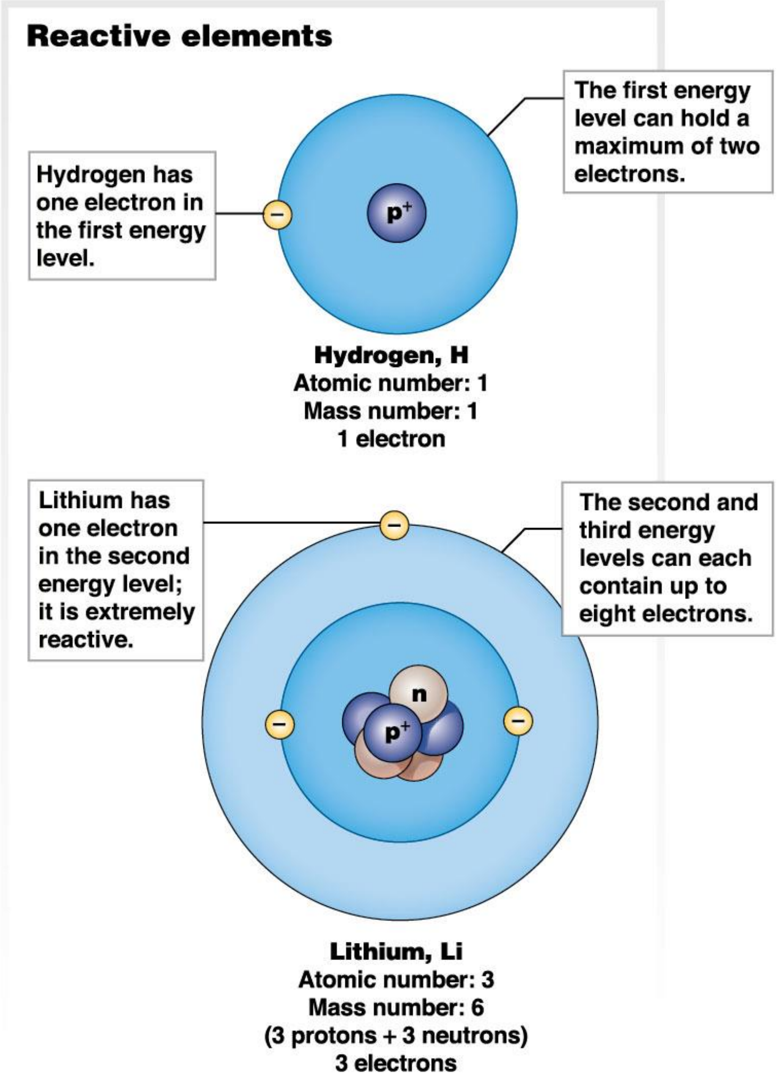
Atoms are electrically neutral

- Every positive proton is balanced by a negative electron
- Electrons occupy an orderly series of energy levels within the electron cloud
  - Can be diagrammed as series of concentric electron shells
  - First shell (closest to nucleus) is the lowest energy level
  - Number of electrons in outermost shell determines chemical properties of element

Module 2.3: Electrons

Energy levels

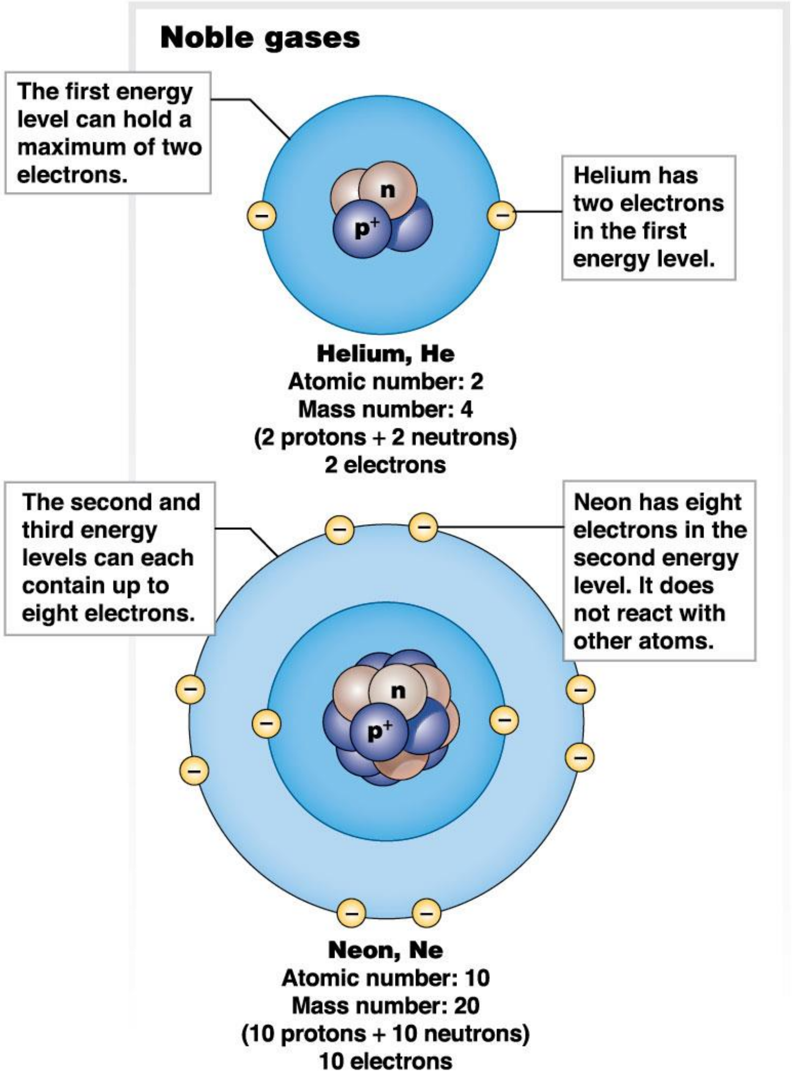
- Outermost energy level (**valence shell**) is atom's "surface"
- Atoms with unfilled outer shells are **reactive**
  - Tend to react with other atoms to fill outer shell
  - *Examples:* hydrogen, lithium



Module 2.3: Electrons

Energy levels (continued)

- Atoms with full outer shells are **inert**
  - Do not readily react with other atoms; more stable
  - *Examples:* helium, neon
    - Called **noble gases**



Module 2.3: Electrons

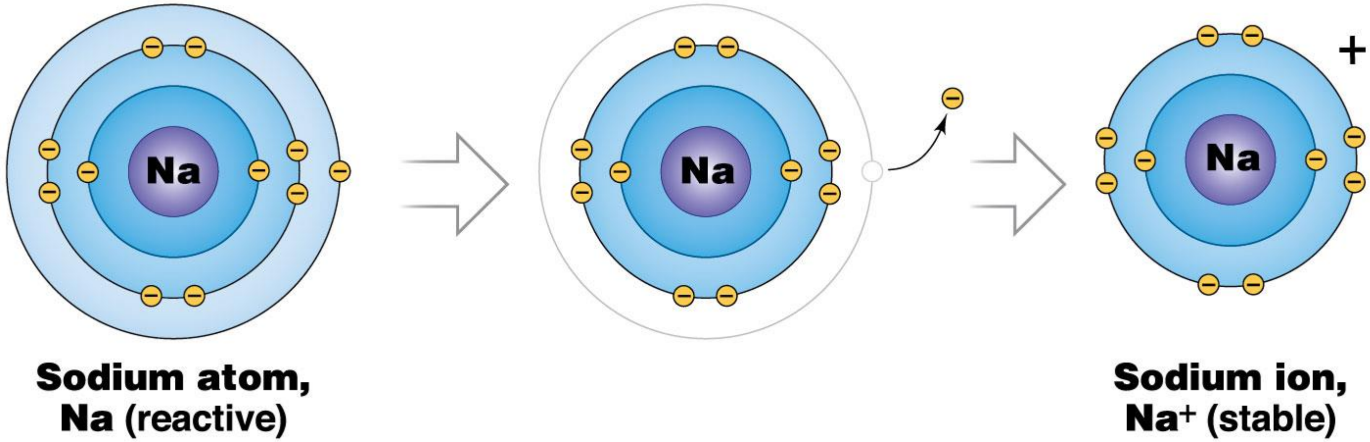
Elements with unfilled valence shells are reactive because they interact and combine together with other atoms

Atoms that have gained or lost electrons are no longer electrically neutral and become ions

Module 2.3: Electrons

Losing an electron means:

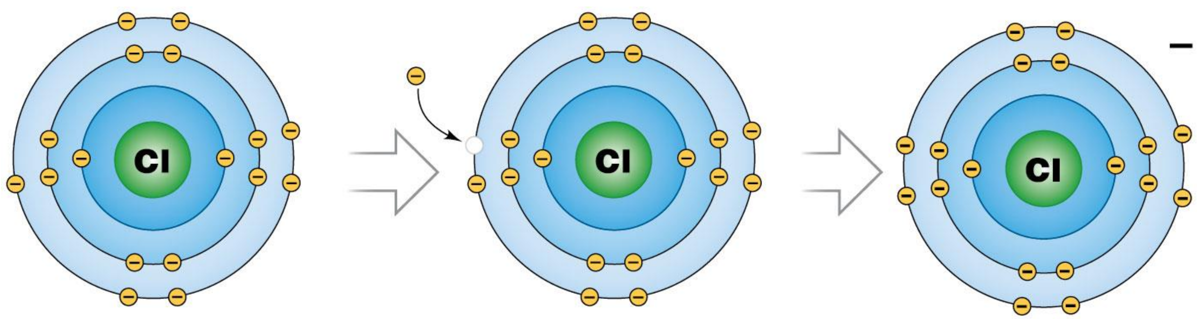
- Fewer electrons (negative) than protons (positive)
- Net positive charge
- Called a positive ion or **cation**
- One missing electron = charge of +1
- More electrons missing = more positive charge (e.g., +2, +3, +4)



Module 2.3: Electrons

Gaining an electron means:

- More electrons (negative) than protons (positive)
- Net negative charge
- Called a negative ion or **anion**
- One extra electron = charge of –1
- More electrons gained = more negative charge (e.g., –2, –3, –4)
- Stabilizing interactions often form **chemical bonds**



Chlorine atom, Cl (reactive)

Chloride ion, Cl⁻ (stable)

Module 2.3: Review

A. Indicate the maximum number of electrons that can occupy each of the first three energy levels of an atom.

B. Explain why the atoms of inert elements do not react with one another or combine with atoms of other elements.

C. Explain how cations and anions form.

D. Cations are smaller in diameter than their electrically neutral atom. Why?

Learning Outcome: Explain the relationship between electrons and energy levels.

Module 2.4: The most common chemical bonds are ionic bonds and covalent bonds

Chemical bonding creates:

- **Compounds**
  - Chemical substance made up of atoms of two or more different elements in a fixed proportion, regardless of type of bond joining them.
- **Molecules**
  - Chemical structure consisting of atoms of one or more elements held together by covalent bonds

Module 2.4: Ionic and covalent bonds

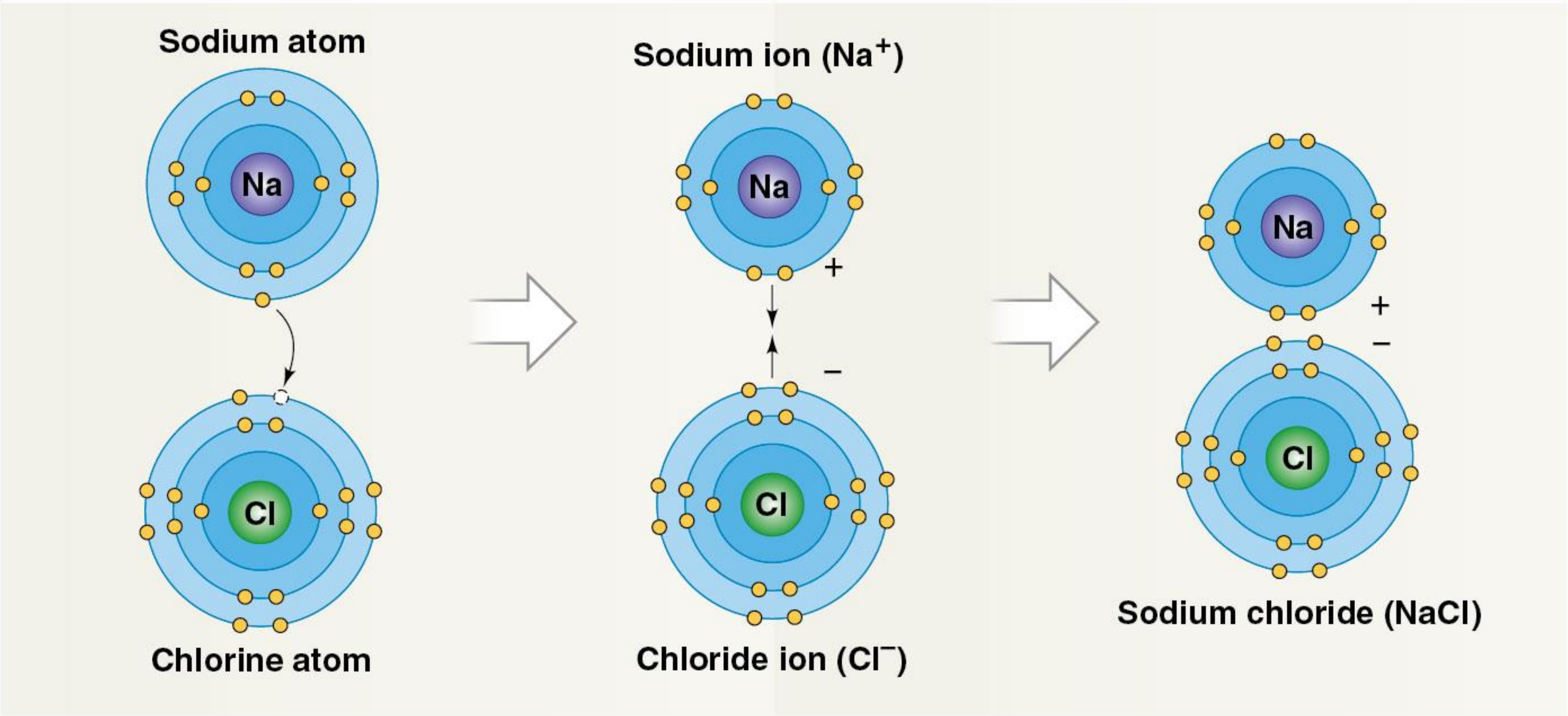
Ionic bonds

- One of the most common types of chemical bonds
- Created by electrical attraction between cations and anions
- Involve transfer of one or more electrons from one atom to another to achieve stability
- *Example:* sodium chloride

Formation of the ionic compound sodium chloride

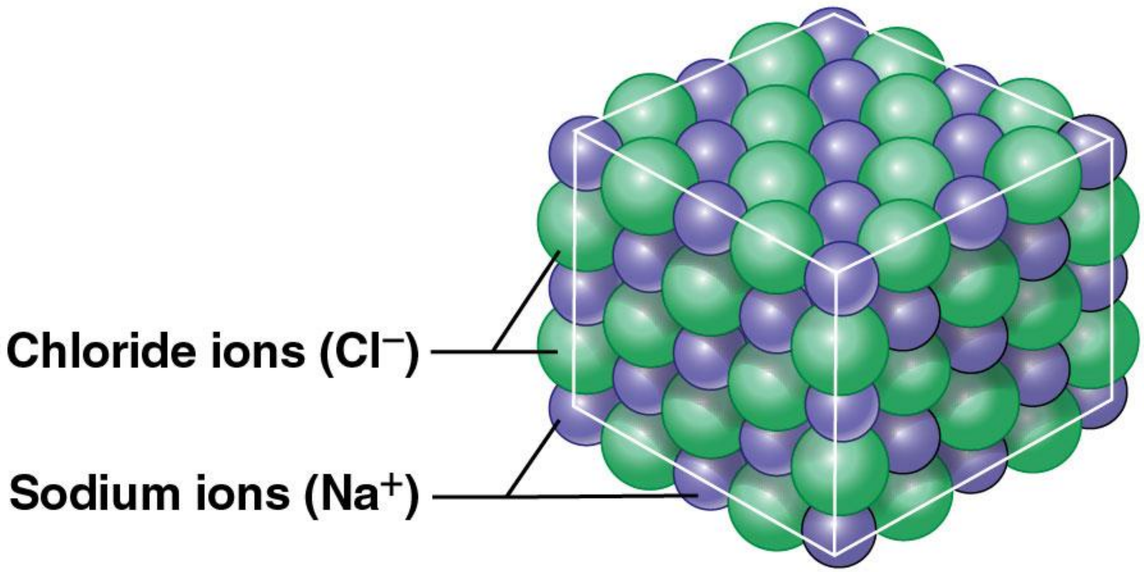
Step 1
Sodium and chloride ion formation. The sodium atom loses an electron to the chlorine atom. This produces two stable ions with filled outer energy levels.

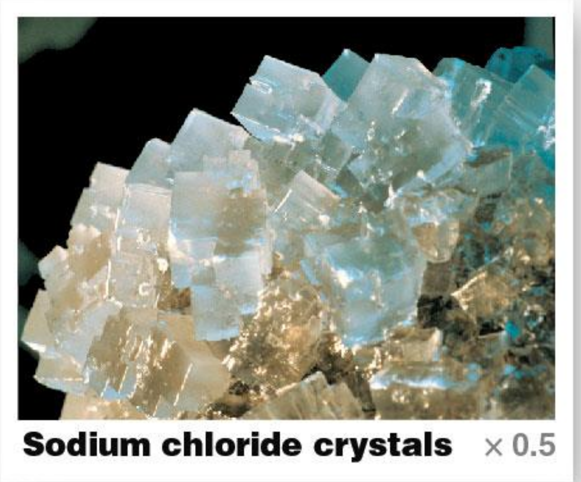
Step 2
Ionic bond formation. Because these ions form close together and have opposite charges, they are attracted to one another. This creates NaCl, an ionic compound.



Module 2.4: Ionic and covalent bonds

- A crystal of sodium chloride contains sodium and chloride ions packed closely together to form the cube shaped crystal



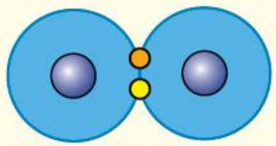
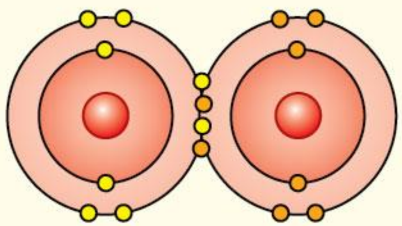
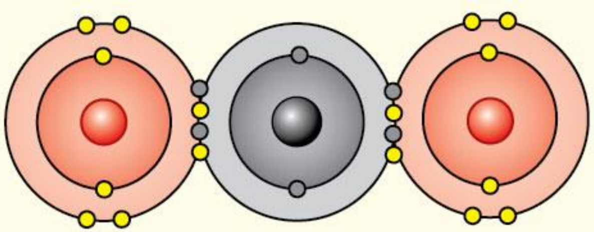


Module 2.4: Ionic and covalent bonds

Covalent bonds

- Involve sharing of electrons between atoms
- Form **molecules**—chemical structure consisting of one or more elements held together by covalent bonds.
- **Single covalent bond**
  - Share one pair of electrons
  - One electron contributed by each atom
- **Double covalent bond**
  - Share two pairs of electrons
  - Two electrons contributed by each atom

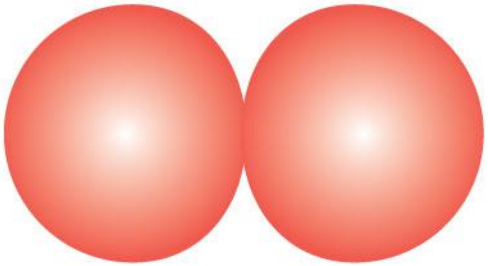
Module 2.4: Ionic and covalent bonds

Molecule	Description
Hydrogen (H_2) 	Hydrogen molecule formed by a **single covalent bond**
Oxygen (O_2) 	Oxygen molecule formed by a **double covalent bond**
Carbon dioxide (CO_2) 	Carbon dioxide molecule formed by two double covalent bonds

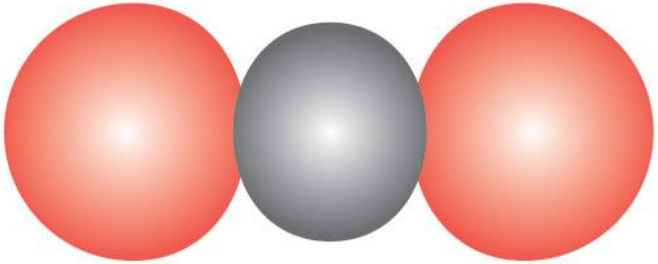
Module 2.4: Ionic and Covalent Bonds

Nonpolar molecule

- Formed by a typical covalent bond
- Electrons shared *equally* between atoms
- No electrical charge on the molecule



Oxygen (O_2)

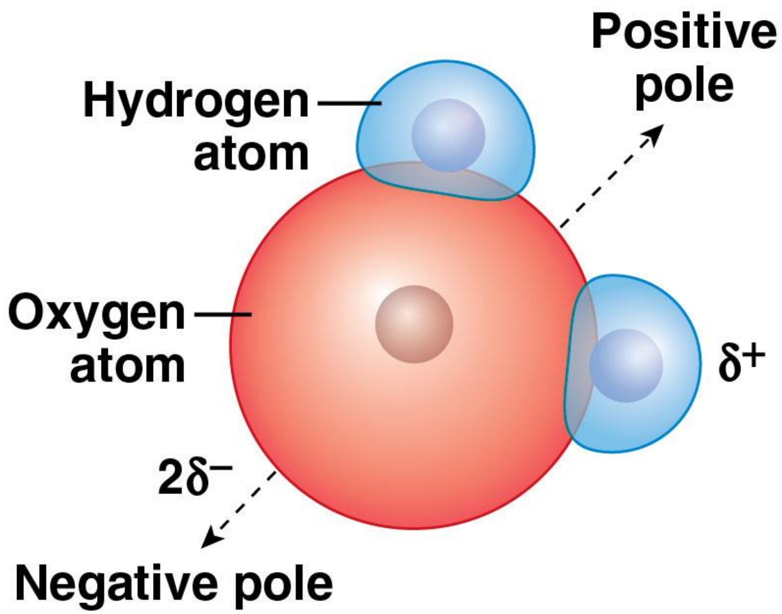


Carbon dioxide (CO_2)

Module 2.4: Ionic and Covalent Bonds

Polar molecule

- Formed by **polar covalent bonds**
- *Unequal* sharing of electrons between atoms
- *Example:* water molecule (H_2O)
  - When electrons spend more time around one atom of a molecule, that atom has a slightly negative charge
  - Oxygen atom attracts electrons a little more and so carries slightly negative charge (δ^-)
  - Hydrogen atoms carry slightly positive charge (δ^+)



Module 2.4: Review

A. Describe why table salt is a compound.
B. How many electrons are shared by the oxygen atoms in the oxygen molecule?
C. Describe the kind of bonds that hold the atoms in a water molecule together.
D. Explain why we can use the term *molecule* for the smallest particle of water but not for that of table salt.

Learning Outcome: Compare the ways in which atoms combine to form molecules and compounds.

Module 2.5: Matter may exist as a solid, a liquid, or a gas

Matter exists in one of three states

1. Solid (particles held tightly together)
    - Maintains volume and shape at ordinary temperatures and pressures

Module 2.5: Three states of matter

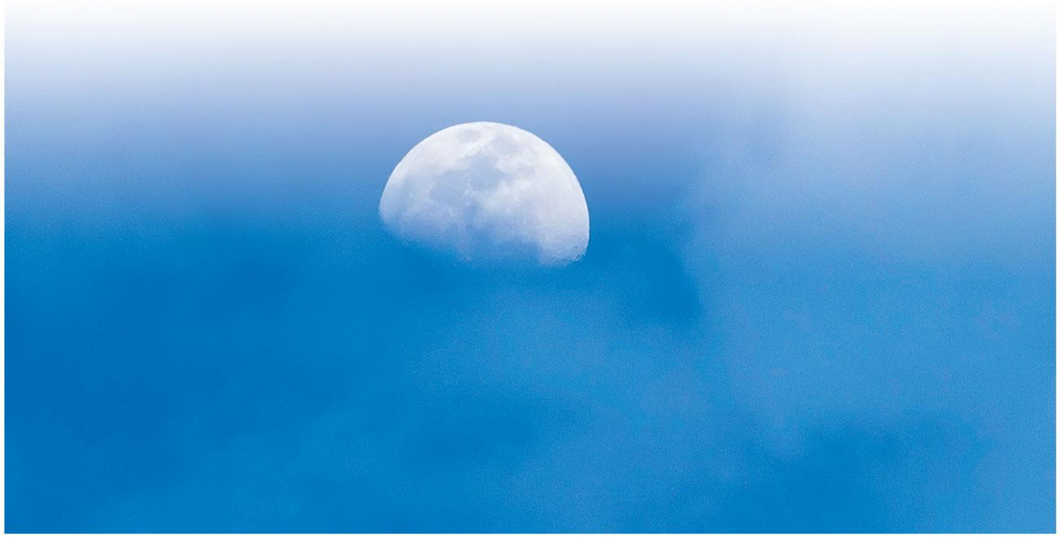
Matter exists in one of three states (continued):

2. Liquid (particles held less tightly together)
   - Has a constant volume
   - Container determines shape

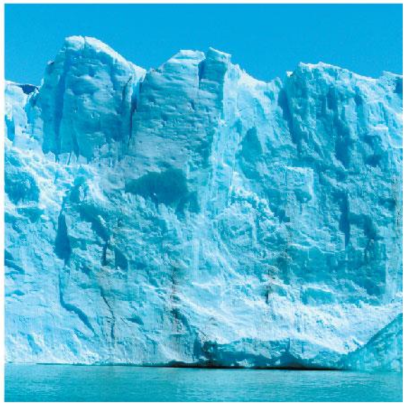
Module 2.5: Three states of matter

Matter exists in one of three states (continued):

3. Gas (particles independent of each other)
   - Has neither a constant volume nor a fixed shape
   - Can be compressed or expanded
   - Will fill a container of any size



Module 2.5: Three states of matter



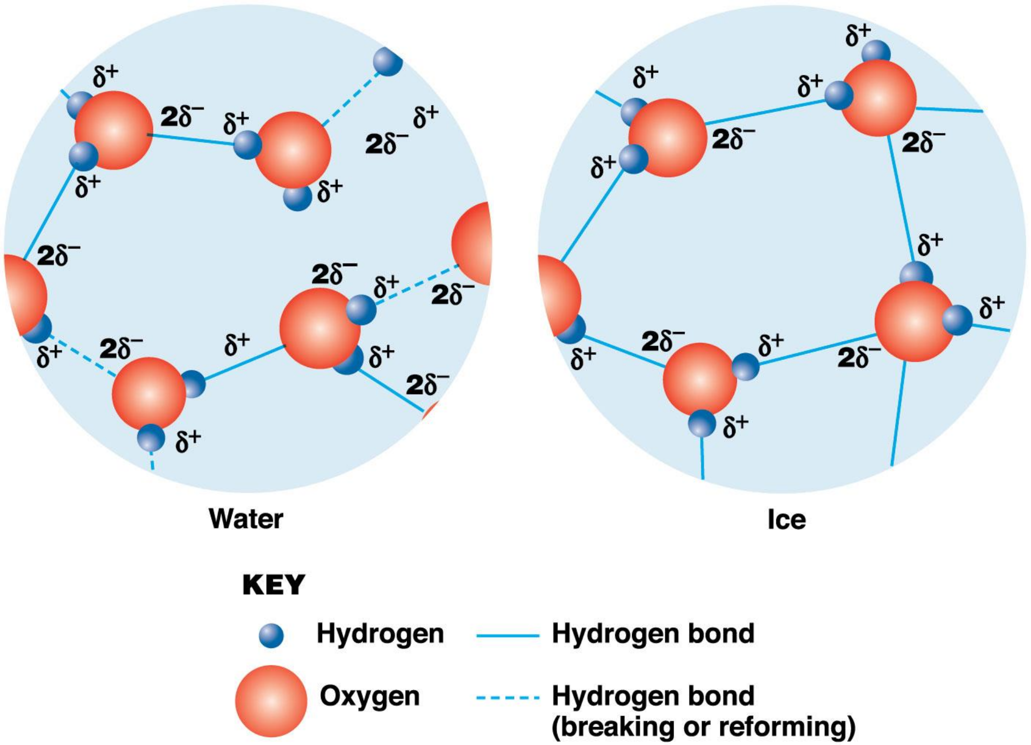
Water: Only substance that exists in all three states of matter at temperatures compatible with life

- Solid (ice)
- Liquid (water)
  - Exists over a broad range of temperatures due to interactions among the polar water molecules
- Gas (water vapor)

Module 2.5: Three states of matter

Hydrogen bond

- Attraction of the small positive charges on hydrogen atoms (of a polar molecule) to negative charges on atoms in other polar molecules
- Can change shape of molecules or pull molecules together



Module 2.5: Three states of matter

Effects of hydrogen bonds on water properties

- Constantly forming and breaking in liquid state
- Lock in place when freezing
  - Accounts for expansion of water when freezing
- Water becomes vapor when all hydrogen bonds broken
- Slows rate of evaporation

Module 2.5: Three states of matter

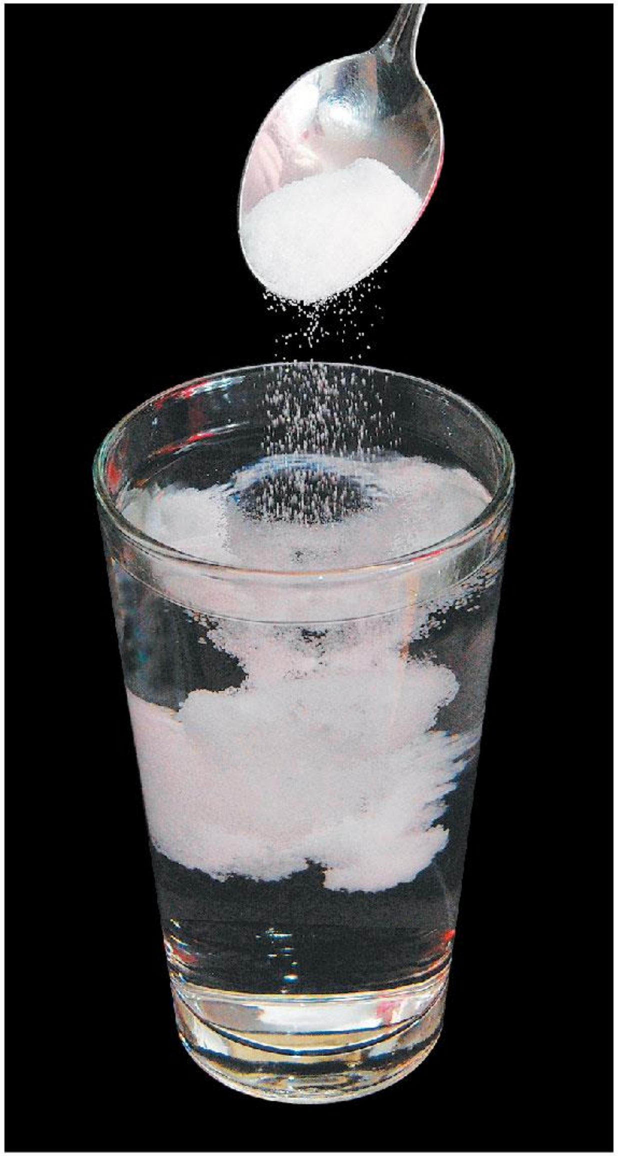
Effects of hydrogen bonds on water properties

- Responsible for **surface tension**
  - Acts as a barrier keeping small objects from entering the water

Module 2.5: Three states of matter

Water as a solvent

- Polar charges on water molecule allow water to disrupt ionic bonds (dissolve) a variety of inorganic compounds
- Seawater contains almost all naturally occurring elements
- Our body fluids contain at least 29 dissolved elements



Module 2.5: Review

A. Describe the different states of matter in terms of shape and volume.
B. By what means are water molecules attracted to each other?
C. Explain why small insects can walk on the surface of a pond and why tears protect the surface of the eye from dust particles.
D. Describe the relationship between thermal energy (temperature) and stability of the hydrogen bonds between water molecules in ice, in liquid water, and as a gas.

Learning Outcome: Describe the three states of matter and the importance of hydrogen bonds in liquid water.

Section 2: Chemical Reactions

Learning Outcomes

2.6 Define metabolism, and distinguish between work, kinetic energy, and potential energy.

2.7 Use chemical notation to symbolize chemical reactions.

2.8 Distinguish among the major types of chemical reactions that are important for studying physiology.

2.9 Describe the crucial role of enzymes in metabolism.

Module 2.6: Chemical reactions and energy transfer are essential to cellular functions

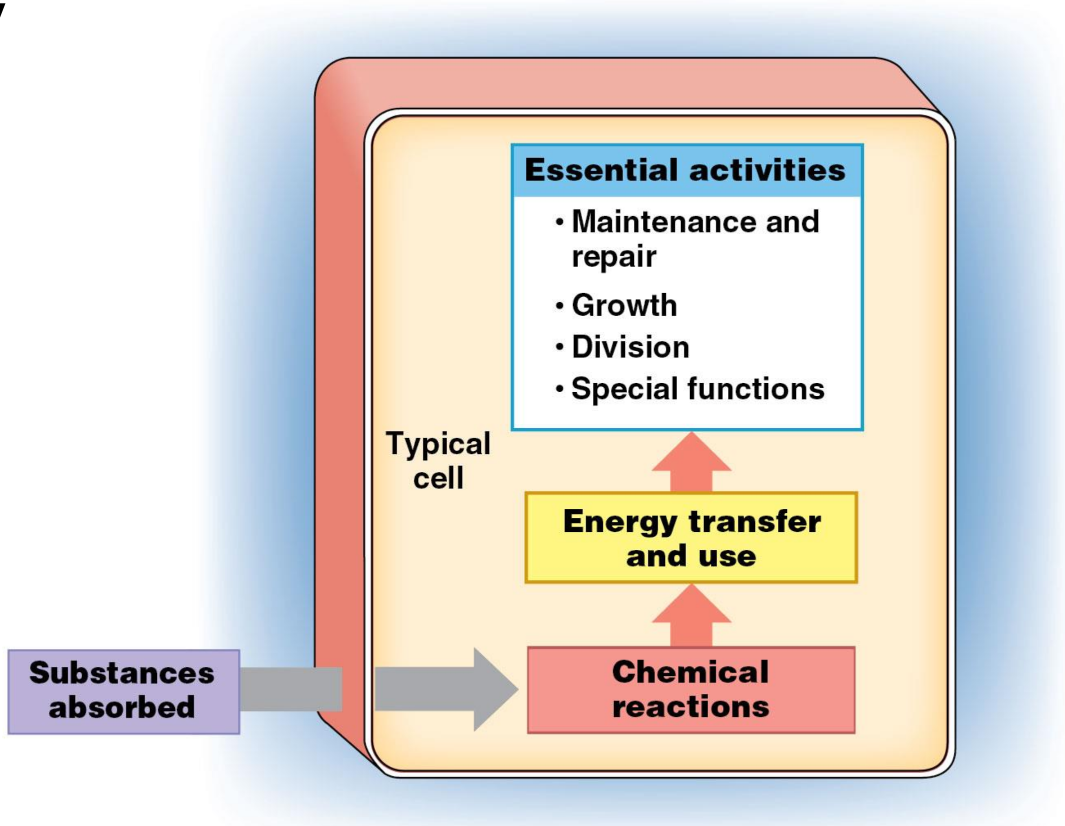
Cells remain alive by controlling chemical reactions

- New chemical bonds are forming
- Existing bonds being broken
- **Reactants**
  - Atoms in the reacting substances
- **Products**
  - Results of the reactions
- **Metabolism**
  - All of the reactions in the body at any moment

Module 2.6: Chemical reactions

Each cell is a "chemical factory"

- Complex chemical reactions are required for essential functions such as:
  - Providing energy
  - Maintenance and repair
  - Growth
  - Cell division
  - Secretion
  - Contraction



Module 2.6: Chemical reactions

Work

- Movement of an object or change in physical structure of matter
- Can be macroscopic (e.g., moving muscles) or microscopic (e.g., synthesis of molecules)

Module 2.6: Chemical reactions

Energy—Capacity to perform work

- **Kinetic energy**
  - Energy of motion
  - Can be transferred to another object and do work
  - *Example:* skeletal muscles contracting
- **Potential energy**
  - Stored energy
  - Has the potential to do work
  - *Example:* a stretched spring
- Conversion of energy is never 100 percent efficient
  - Some energy is released as heat
  - *Example:* body temperature rises as muscles contract

Module 2.6: Review

A. Describe how cells are chemical factories.

B. Compare and contrast the terms *work, energy, potential energy,* and *kinetic energy*.

C. Relate the terms *work, energy, potential energy,* and *kinetic energy* to a muscle contraction at the cellular level.

Learning Outcome: Define *metabolism*, and distinguish among work, kinetic energy, and potential energy.

Module 2.7: Chemical notation is a concise method of describing chemical reactions

Chemical notation

- Simple “chemical shorthand”
- Allows precise and brief description of complex events
- May be used to calculate weights of reactants in a reaction

Module 2.7: Chemical notation

Chemical notation for atoms

- Symbol of element indicates one **atom** of that element
  - H = one atom of hydrogen
  - O = one atom of oxygen
- Number preceding symbol indicates more than one atom of that element
  - 2 H = two atoms of hydrogen
  - 2 O = two atoms of oxygen

Module 2.7: Chemical notation

Chemical notation for molecules

- Subscript following symbol indicates a **molecule** with that number of atoms of that element
  - H_2 = hydrogen molecule, composed of two hydrogen atoms
  - O_2 = oxygen molecule, composed of two oxygen atoms
  - H_2O = water molecule, composed of two hydrogen atoms and one oxygen atom

Module 2.7: Chemical notation

Chemical reactions

- Reactants
  - Participants at reaction start
  - Usually on the left
- Products
  - Generated at end of reaction
  - Usually on the right
- Arrow indicates direction of reaction from reactants to products
- Represented by chemical equations
  - *Example:* $2\ H + O \rightarrow H_2O$

Module 2.7: Chemical notation

Chemical reactions (continued)

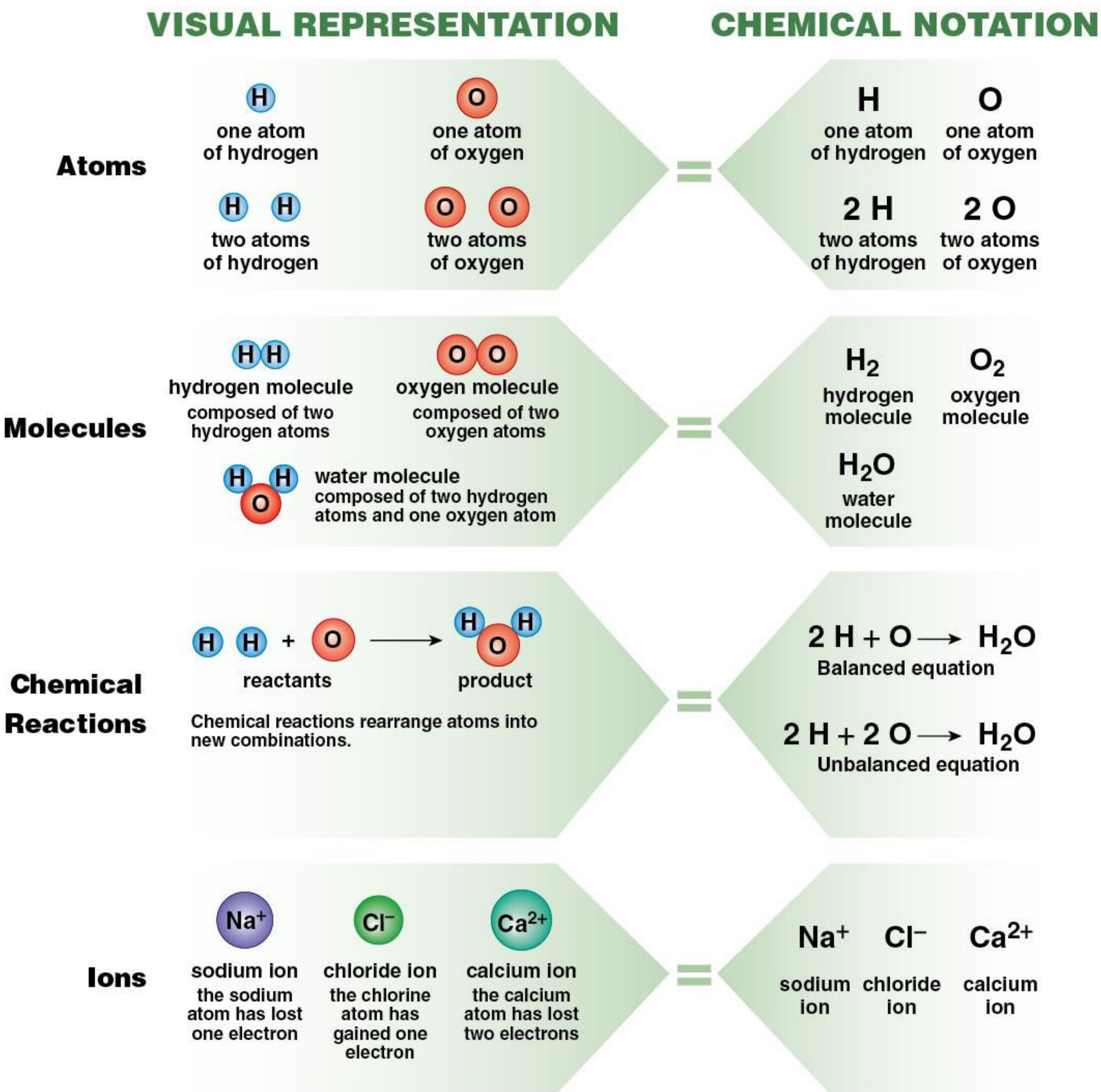
- Chemical reactions rearrange atoms into new combinations
- Number of atoms must be the same on both sides of the equation to be balanced
  - Example of balanced equation
    - $2\ H_2 + O_2 \rightarrow 2\ H_2O$
  - Example of unbalanced equation
    - $H_2 + O_2 \rightarrow H_2O$

Module 2.7: Chemical notation

Chemical notation for ions

- A superscript plus or minus following symbol indicates an **ion**
  - Single plus sign indicates cation with +1
    - Atom has lost one electron
    - *Example:* Na^+
  - Single minus sign indicates anion with –1
    - Atom has gained one electron
    - *Example:* Cl^-
  - Number before sign indicates more than one electron lost or gained
    - *Example:* Ca^{2+}

Chemical notation

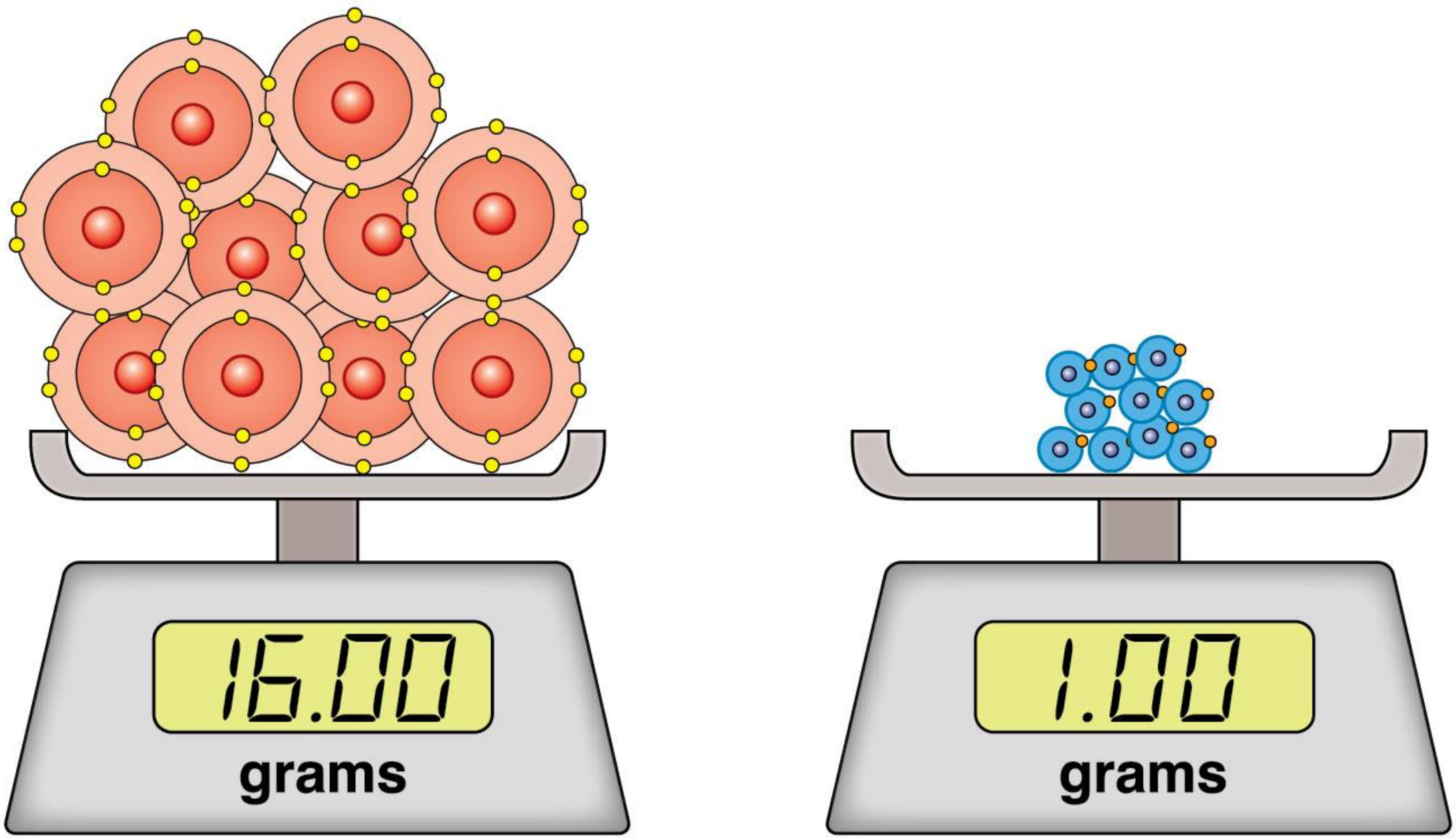


Module 2.7: Chemical notation

Mole (mol)

- Quantity with a weight (in grams) equal to an element's atomic weight
- One mole of a given element always contains the same number of atoms as one mole of another element
  - *Examples:*
    - Atomic weight of oxygen = 16
    - 1 mole of oxygen = 16 grams
    - Atomic weight of hydrogen = 1
    - 1 mole of hydrogen = 1 gram

A mole is a quantity with a weight in grams equal to an element's atomic weight



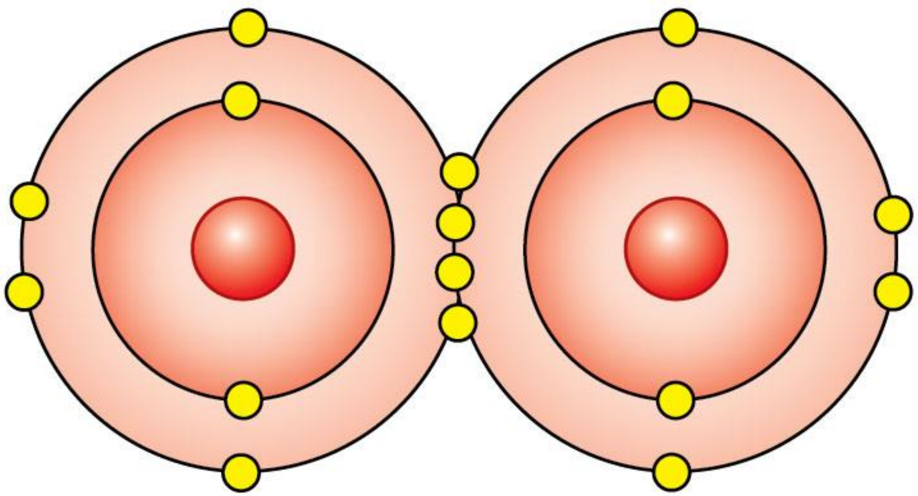
1 mol of oxygen

1 mol of hydrogen

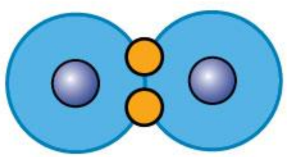
Module 2.7: Chemical notation

Molecular weight

- Sum of the atomic weights of all atoms making up a molecule
  - For ionic compounds, use the term **formula weight**



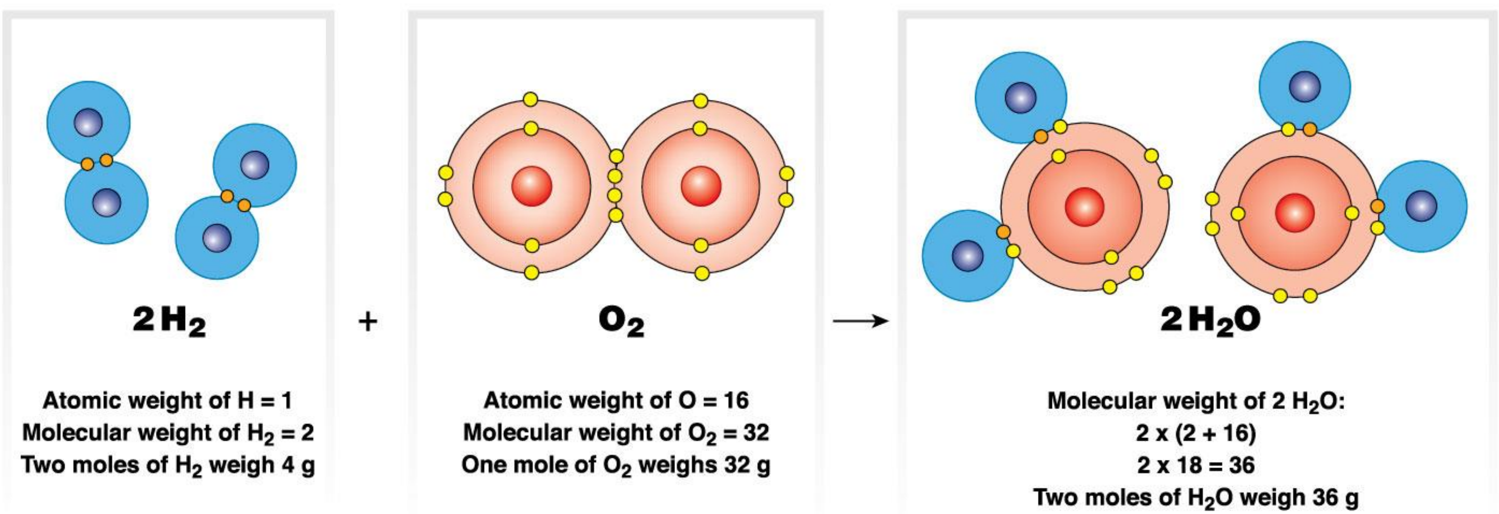
Molecular weight of O_2 = 32



Molecular weight of H_2 = 2

Module 2.7: Chemical notation

- Simplify calculations of moles and molecular weights by rounding atomic weights to nearest whole number
- Molecular weights can be used to calculate quantities of reactants or products for a chemical reaction
- Calculate molecular weights of reactants and the sum will equal the molecular weight of the products



Module 2.7: Review

A. Name the participants in a chemical reaction.
B. How are chemical reactions represented?
C. What is formula weight?
D. Using chemical notation, write the molecular formula for glucose, a compound composed of 6 carbon (C) atoms, 12 hydrogen (H) atoms, and 6 oxygen (O) atoms.
E. Calculate the weight of 1 mol of glucose. (The atomic weight of carbon = 12.)

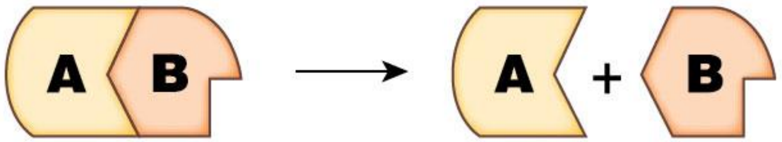
Learning Outcome: Use chemical notation to symbolize chemical reactions.

Module 2.8: Three basic types of chemical reactions are important for understanding physiology

Decomposition reactions

- Break a molecule into smaller fragments
- Occur inside and outside cells
- Example
  - Digestion of food for absorption

$$AB \longrightarrow A + B$$

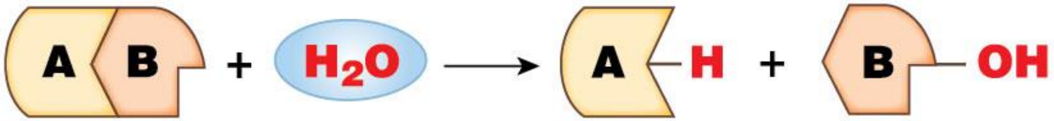


Module 2.8: Types of chemical reactions

Decomposition reactions (continued)

- **Hydrolysis**
  - Specific type of decomposition reaction that involves water.
  - One of the bonds in a molecule is broken
  - Components of water molecule (H and OH) are added to the fragments

$$AB + H_2O \longrightarrow AH + BOH$$

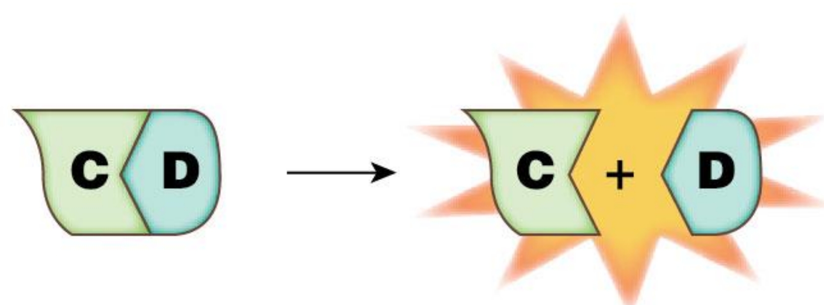


Module 2.8: Types of chemical reactions

Decomposition reactions (continued)

- **Catabolism** (*katabole*, a throwing down)
  - Collective term for decomposition reactions in the body
  - Refers to breaking covalent bonds (form of potential energy)
  - Release kinetic energy that can perform work
  - Body can use energy for growth, movement, and reproduction

$$CD \longrightarrow C + D + \text{ENERGY}$$

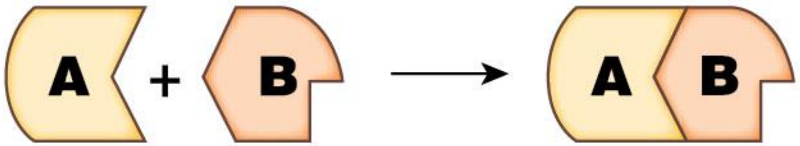


Module 2.8: Types of chemical reactions

Synthesis reactions

- Opposite of decomposition
- Assemble smaller molecules into larger molecules
- Always involve formation of new chemical bonds

$$A + B \longrightarrow AB$$

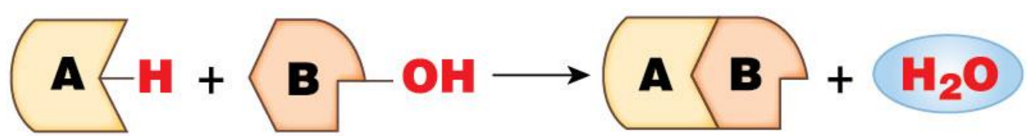


Module 2.8: Types of chemical reactions

Synthesis reactions (continued)

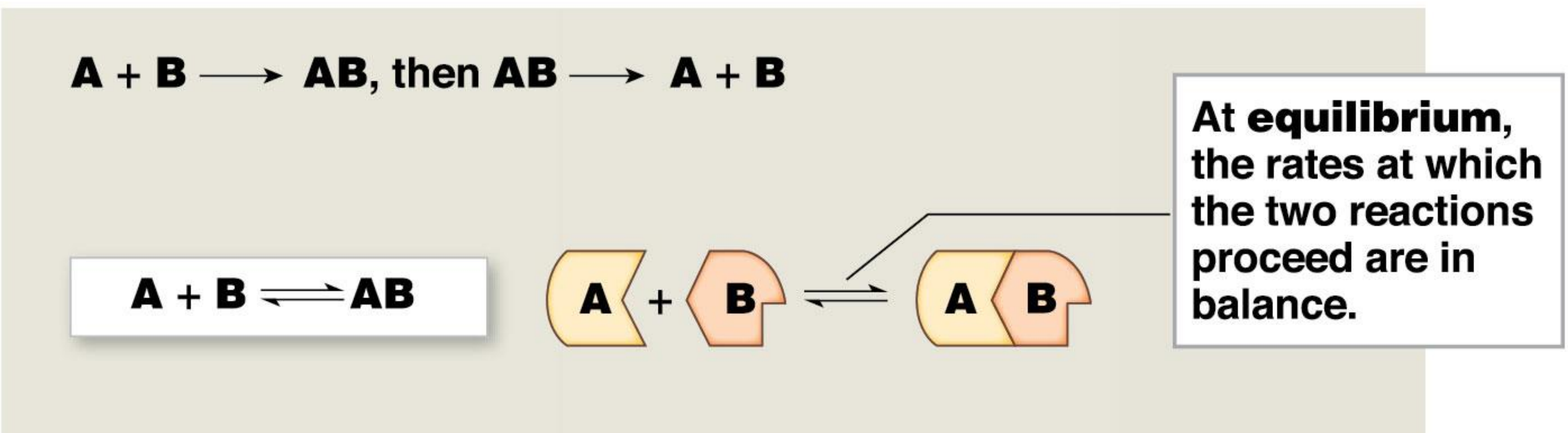
- **Dehydration synthesis** (condensation)
  - Formation of a complex molecule by removing a water molecule
  - Opposite of hydrolysis
- **Anabolism** (*anabole*, a throwing upward)
  - Collective term for synthesis reactions
  - Refers to forming new chemical bonds
  - Requires energy
  - Energy usually comes from other catabolic reactions

$$AH + BOH \longrightarrow AB + H_2O$$



Module 2.8: Types of Chemical Reactions

- Decomposition and synthesis reactions are often coupled together
  - Many biological reactions are freely reversible (they can operate in either direction)
- At **equilibrium**, rates of both reactions are in balance

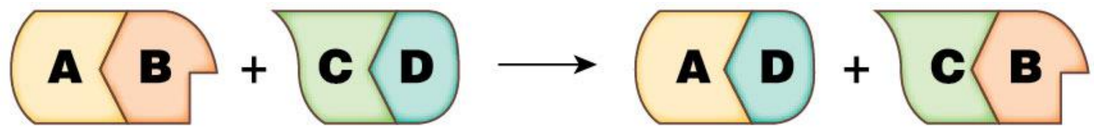


Module 2.8: Types of Chemical Reactions

Exchange reactions

- Parts of the reacting molecules are shuffled around to produce new products
- May involve both decomposition and synthesis reactions

$$AB + CD \longrightarrow AD + CB$$



Module 2.8: Review

A. Compare the role of water in hydrolysis and dehydration synthesis reactions.
B. Identify and describe three types of chemical reactions important in human physiology.
C. What is the source of the energy that converts glucose, a six-carbon molecule, into two three-carbon molecules in cells?

Learning Outcome: Distinguish among the major types of chemical reactions that are important for studying physiology.

Module 2.9: Enzymes lower the activation energy requirements of chemical reactions

Most chemical reactions require energy to activate reactants

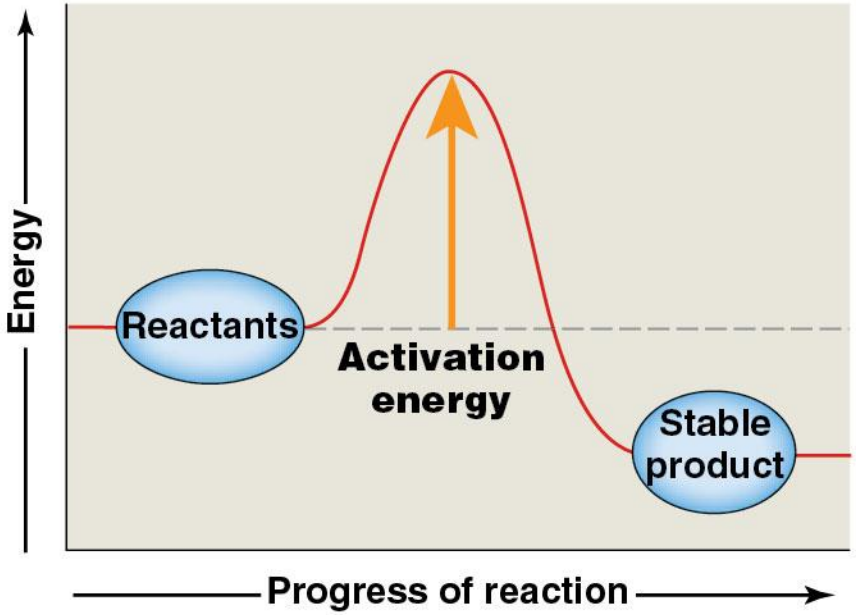
- **Activation energy**
  - Minimum energy required to activate reactants in a reaction and allow reaction to proceed
  - Outside the body, may be acquired by extremes in temperature, pressure, or lethal chemical factors
  - Inside the body, cells use special proteins called **enzymes**

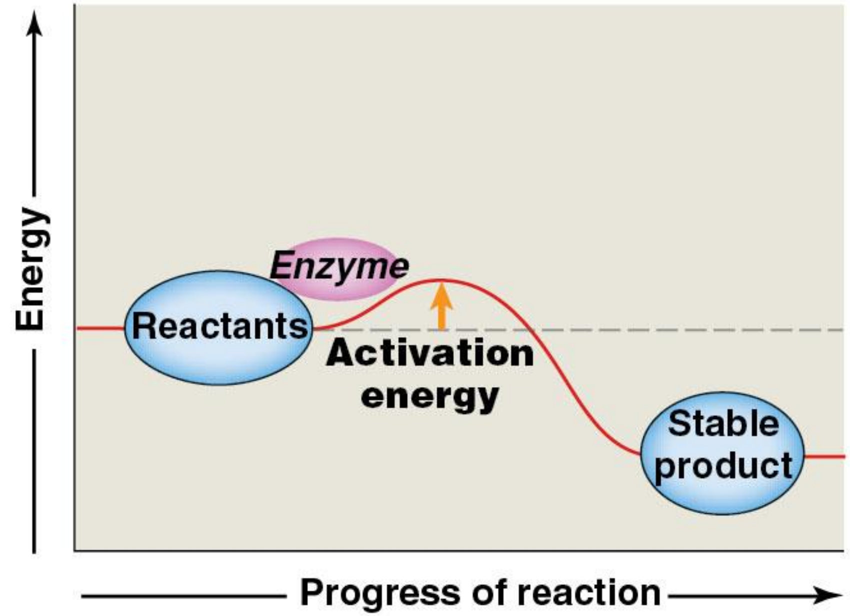
Module 2.9: Enzymes

Enzymes

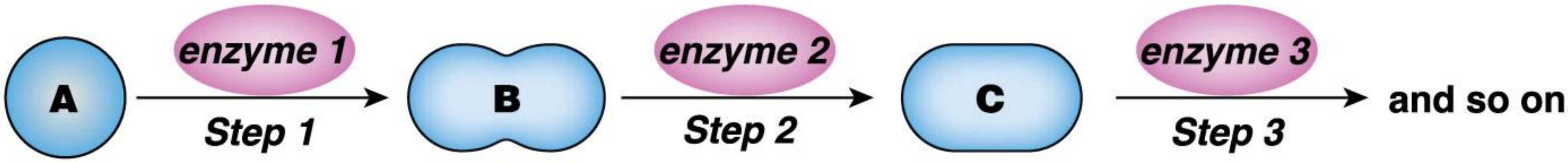
- Promote chemical reactions
- Lower the required activation energy
- Allow reactions to proceed under conditions compatible with life
- Function as **catalysts** (*katalysis*, dissolution)
  - Accelerate chemical reaction without being permanently changed or consumed
  - Reactions continue until equilibrium is reached

Enzymes lower activation energy





Module 2.9: Enzymes



Metabolic pathway

- Series of complex reactions occurring in the body
- Each reaction interlocking with next step
- Each reaction controlled by specific enzyme

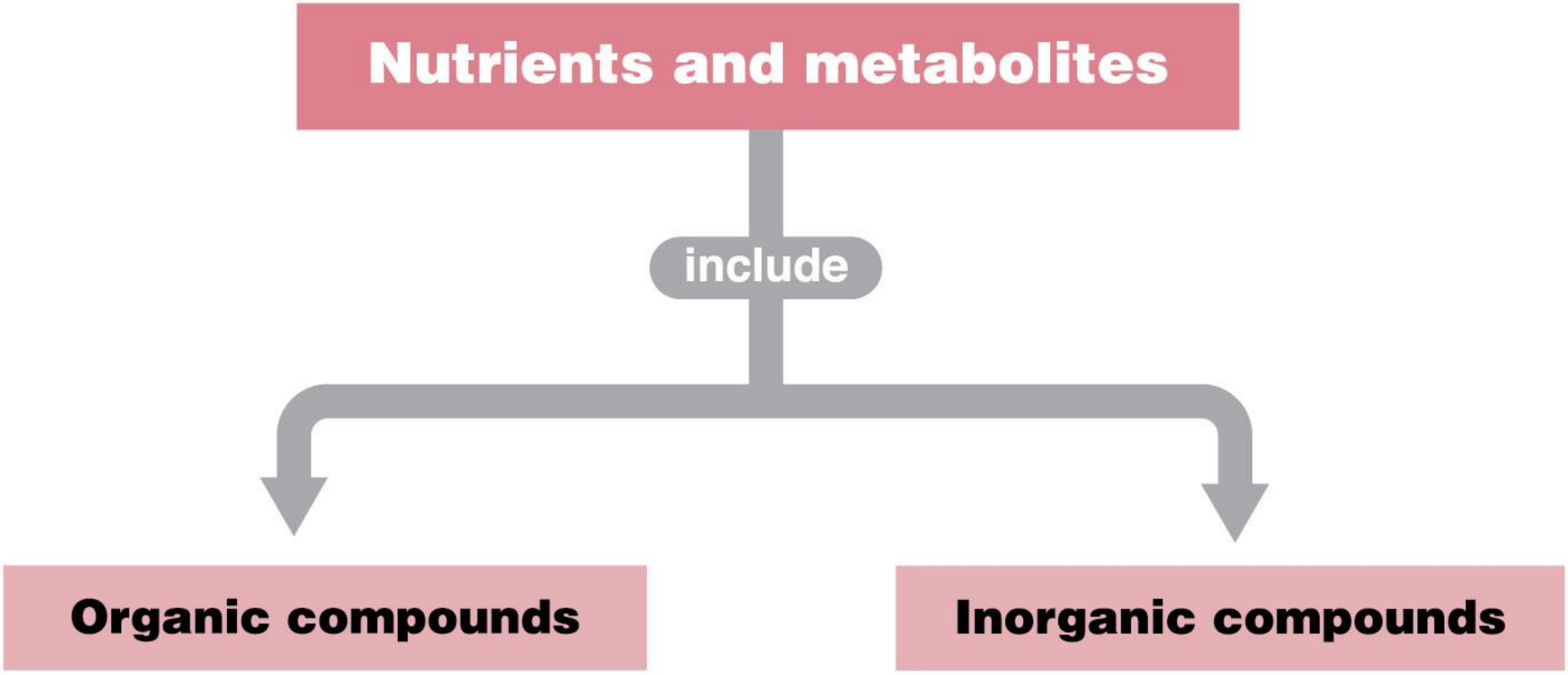
Module 2.9: Enzymes

- Reactions may absorb or release energy on completion
  - **Exergonic** (*exo*-, outside)
    - Overall net release of energy
    - Common in the body and help to maintain body temperature
  - **Endergonic** (*endo*-, inside)
    - More energy is required to begin than is released
    - Include reactions to build molecules

Module 2.9: Enzymes

Metabolites (*metabole*, change)

- Substances synthesized or decomposed in our bodies
- Processed by enzymatic reactions



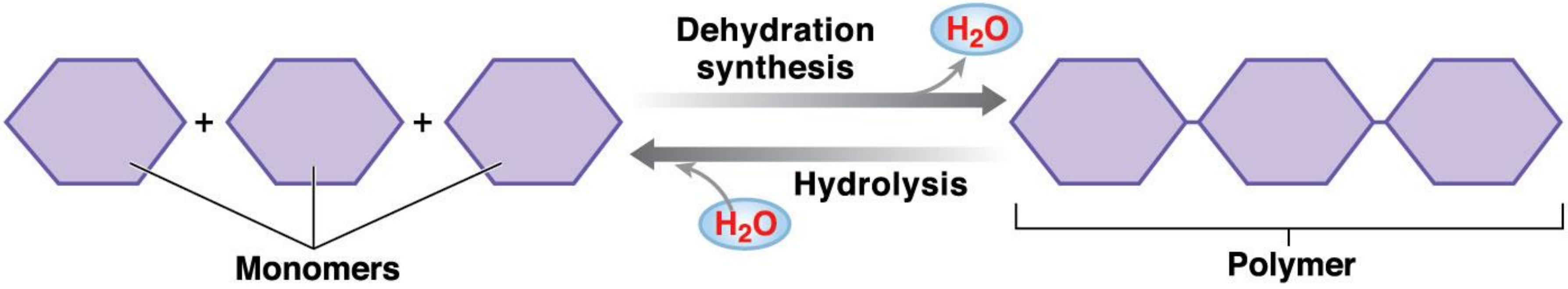
Module 2.9: Enzymes

Nutrients

- Essential metabolites normally obtained from our diet
- Can be classified as:
  - **Organic compounds**
    - Always contain carbon and hydrogen
    - *Examples:* sugars, fats, proteins
  - **Inorganic compounds**
    - Generally do not contain carbon and hydrogen
    - *Examples:* carbon dioxide, water, salts

Module 2.9: Enzymes

- **Macromolecule**—large molecule made up of monomer subunits
- **Monomer**—molecule that can be bonded to other identical molecules to form a **polymer**
- Repeating monomers join through dehydration synthesis to form polymers
- Hydrolysis reactions separate polymers to form monomers



Module 2.9: Review

A. What is an enzyme?
B. Why do our cells need enzymes?
C. What is an important by-product of exergonic reactions?
D. Explain the differences between metabolites and nutrients.
E. Explain why enzymes are often called organic catalysts.

Learning Outcome: Describe the crucial role of enzymes in metabolism.

Section 3: Water in the Body

Learning Outcomes

2.10 Describe four important properties of water and their significance in the body.

2.11 Explain how the chemical properties of water affect the solubility of inorganic and organic molecules.

2.12 Discuss the importance of pH and the role of buffers in body fluids.

Module 2.10: Water has several important properties

Water

- Most important component of your body
- Makes up about 2/3 of total body weight
- Affects all physiological systems

Module 2.10: Water in the body

Important properties of water

- **Lubrication**
  - Little friction between water molecules, so thin layer of water reduces friction between surfaces

Lubrication

Water is an effective lubricant, reducing friction within joints and in body cavities.

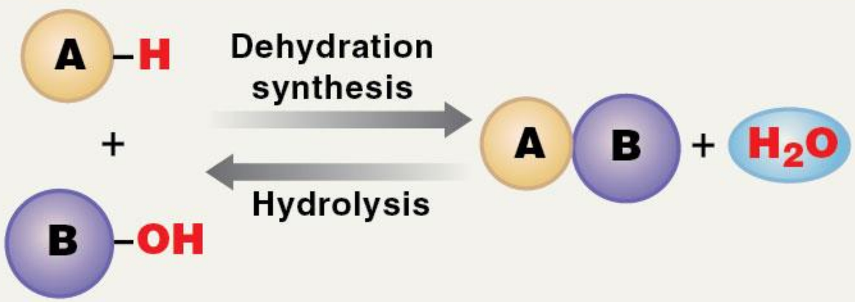
Module 2.10: Water in the body

Important properties of water (continued)

- **Chemical reactant**
  - Water molecules are participants in many reactions such as dehydration synthesis and hydrolysis
  - Chemical reactions occur in water

Chemical reactant

Chemical reactions occur in water.



Module 2.10: Water in the body

Important properties of water (continued)

- **High heat capacity**
  - **Heat capacity** = quantity of heat required to raise temperature of a unit mass of a substance 1ºC
  - To change from liquid to gas, hydrogen bonds between water molecules must be broken, which requires energy (so more heat required)
  - Water carries heat with it when changing from liquid to gas (e.g., evaporation of perspiration on the skin)
  - **Thermal inertia**
    - Refers to large mass of water changing temperature very slowly.

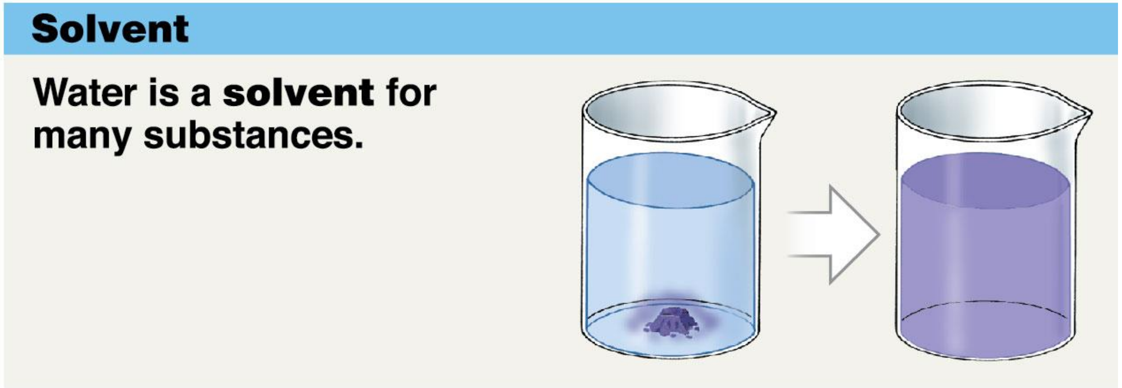
High heat capacity

Water has a high **heat capacity**

Module 2.10: Water in the body

Important properties of water (continued)

- **Solvent**
  - Both inorganic and organic molecules dissolve in water
  - **Solvent**—the liquid in which other atoms, ions, or molecules are distributed
  - **Solute**—the dissolving substances
  - **Solution**—a uniform mixture of two or more substances
  - **Aqueous solutions**—where water is the solvent



Module 2.10: Review

A. Predict how water plays a role as a lubricant, reactant, coolant, and solvent during exercise.

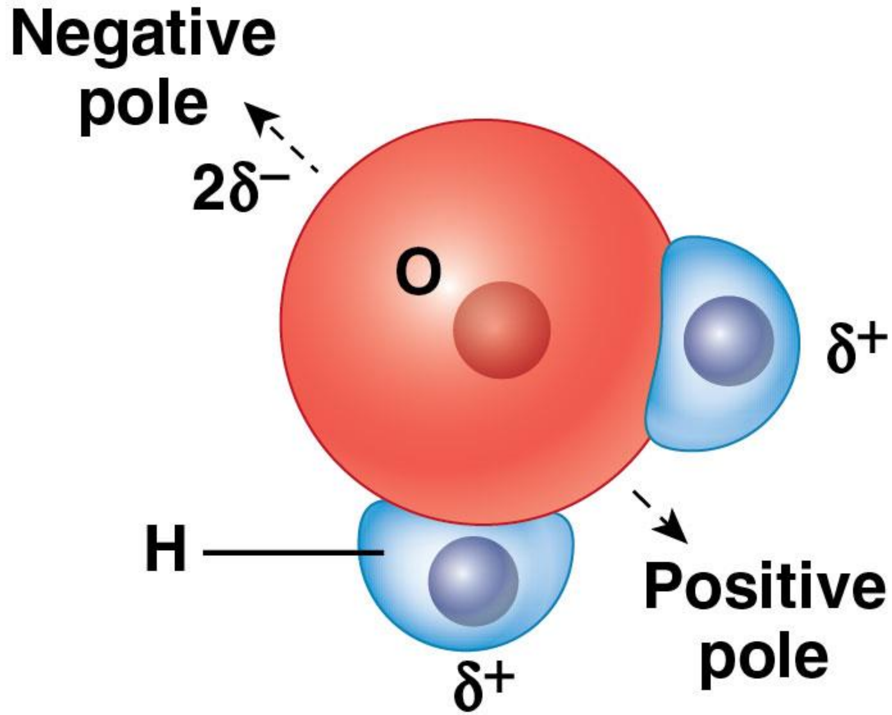
Learning Outcome: Describe four important properties of water and their significance in the body.

Module 2.11: Physiological systems depend on water

Many inorganic compounds are held together by ionic bonds

- **Ionization** or **dissociation**
  - Process of breaking ionic bonds as ions interact with poles of a water molecule

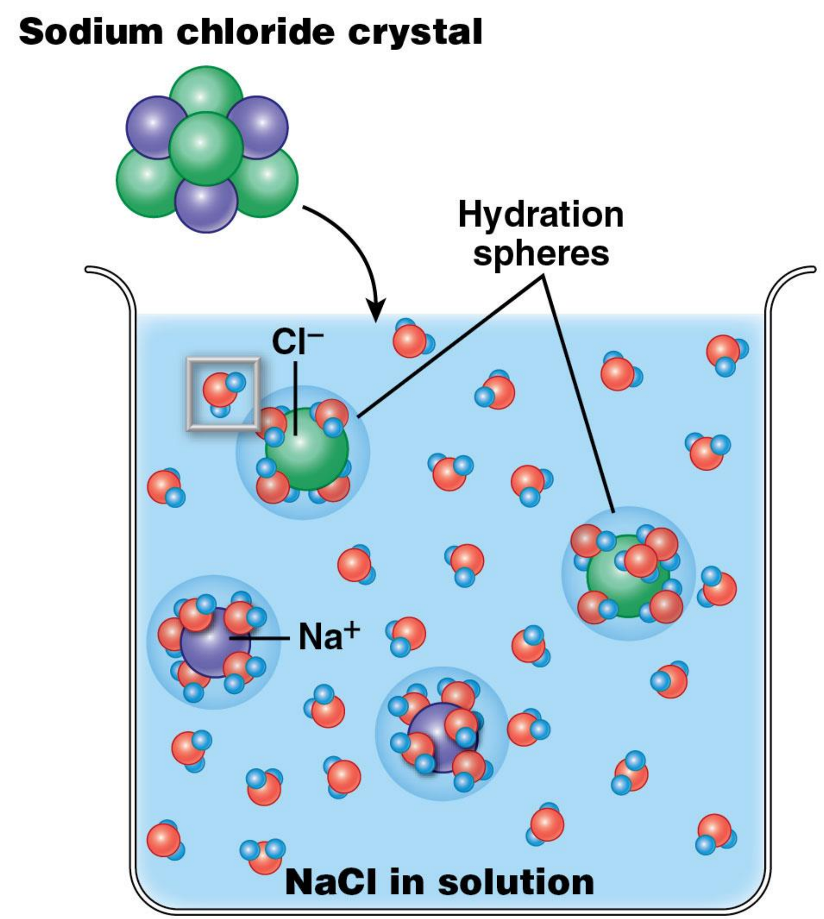
Water is polar due to the polar covalent bonds



Module 2.11: Physiological systems depend on water

In an aqueous solution:

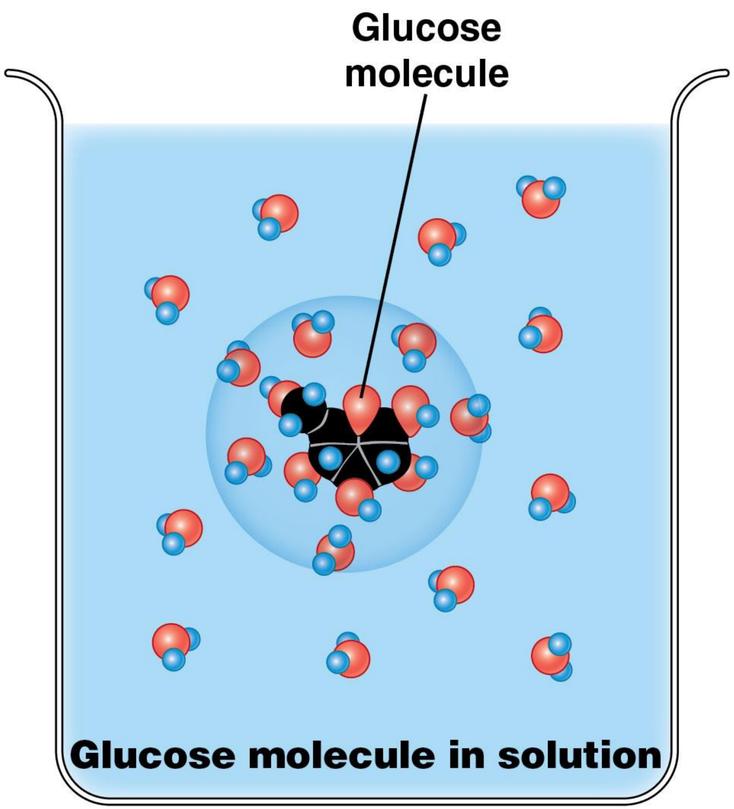
- Anions (negative ions) surrounded by positive poles of water molecules
- Cations (positive ions) surrounded by negative poles of water molecules
- **Hydration spheres**
  - A layer of water molecules around an ion in solution



Module 2.11: Physiological systems depend on water

Molecules with polar covalent bonds also attract water molecules

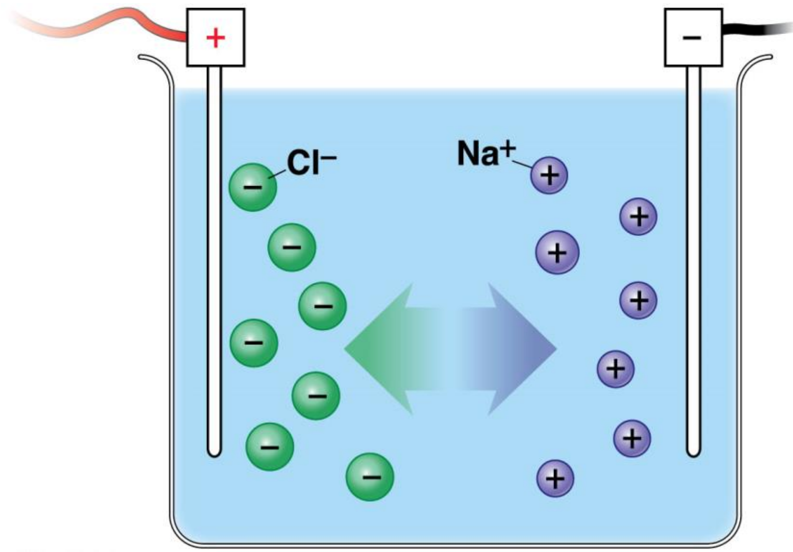
- Water forms hydration sphere around the molecule
- If the molecule binds to water strongly, it will dissolve
  - **Hydrophilic** (*hydro-*, water + *philos*, loving)
  - Molecules that interact with water readily
  - *Examples:* glucose



Module 2.11: Physiological systems depend on water

Aqueous solution with anions and cations will conduct electrical current

- **Electrolytes**—soluble inorganic substances whose ions will conduct electrical current
  - *Example:* NaCl → Na^+ + Cl^-
- In an electrical field:
  - Cations move toward negative terminal
  - Anions move toward positive terminal



Module 2.11: Physiological systems depend on water

Electrolytes (continued)

- Electrical forces across plasma membrane affect all cells in body
- Small electrical currents essential to nerve and muscle function
- Ion concentration in body fluids is carefully regulated by:
  - Kidneys (ion excretion)
  - Digestive tract (ion absorption)
  - Skeletal system (ion storage or release)

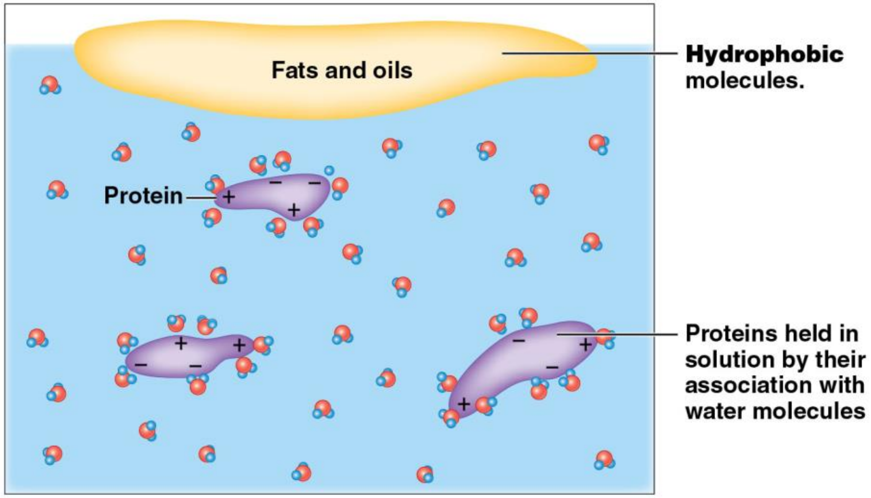
Important Electrolytes That Dissociate in Body Fluids

Electrolyte		Ions Released
$NaCl$ (sodium chloride)	$\longrightarrow$	$Na^{+} + Cl^{-}$
KCl (potassium chloride)	$\longrightarrow$	$K^{+} + Cl^{-}$
$CaPO_4$ (calcium phosphate)	$\longrightarrow$	$Ca^{2+} + PO_4^{2-}$
$NaHCO_3$ (sodium bicarbonate)	$\longrightarrow$	$Na^{+} + HCO_3^{-}$
$MgCl_2$ (magnesium chloride)	$\longrightarrow$	$Mg^{2+} + 2\ Cl^{-}$
Na_2HPO_4 (sodium hydrogen phosphate)	$\longrightarrow$	$2\ Na^{+} + HPO_4^{2-}$
Na_2SO_4 (sodium sulfate)	$\longrightarrow$	$2\ Na^{+} + SO_4^{2-}$

Module 2.11: Physiological systems depend on water

Many organic molecules lack or have very few polar covalent bonds

- Nonpolar = no positive or negative poles
- No hydration spheres form because no poles for water molecules to be attracted to
- Molecules do not dissolve
- **Hydrophobic** (*hydro-*, water + *phobos*, fear)
  - Do not readily interact with water
- *Examples:* fats and oils



Module 2.11: Physiological systems depend on water

Large organic molecules often held in solution by water molecules

Colloid

- Solution containing dispersed proteins or other large molecules
- Remain in solution indefinitely
- *Example:* liquid Jell-O

Suspension

- Solution containing larger particles
- Particles will settle out if undisturbed
- *Example:* whole blood

Module 2.11: Review

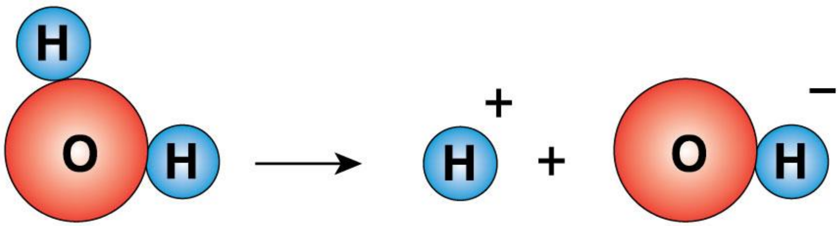
A. Explain how the ionic compound sodium chloride dissolves in water.

B. Define *electrolytes*.

C. Distinguish between hydrophilic and hydrophobic molecules.

Learning Outcome: Explain how the chemical properties of water affect the solubility of inorganic and organic molecules.

Module 2.12: Regulation of body fluid pH is vital for homeostasis



Water (H_2O) can dissociate into hydrogen ions (H^+) and hydroxide ions (OH^-)

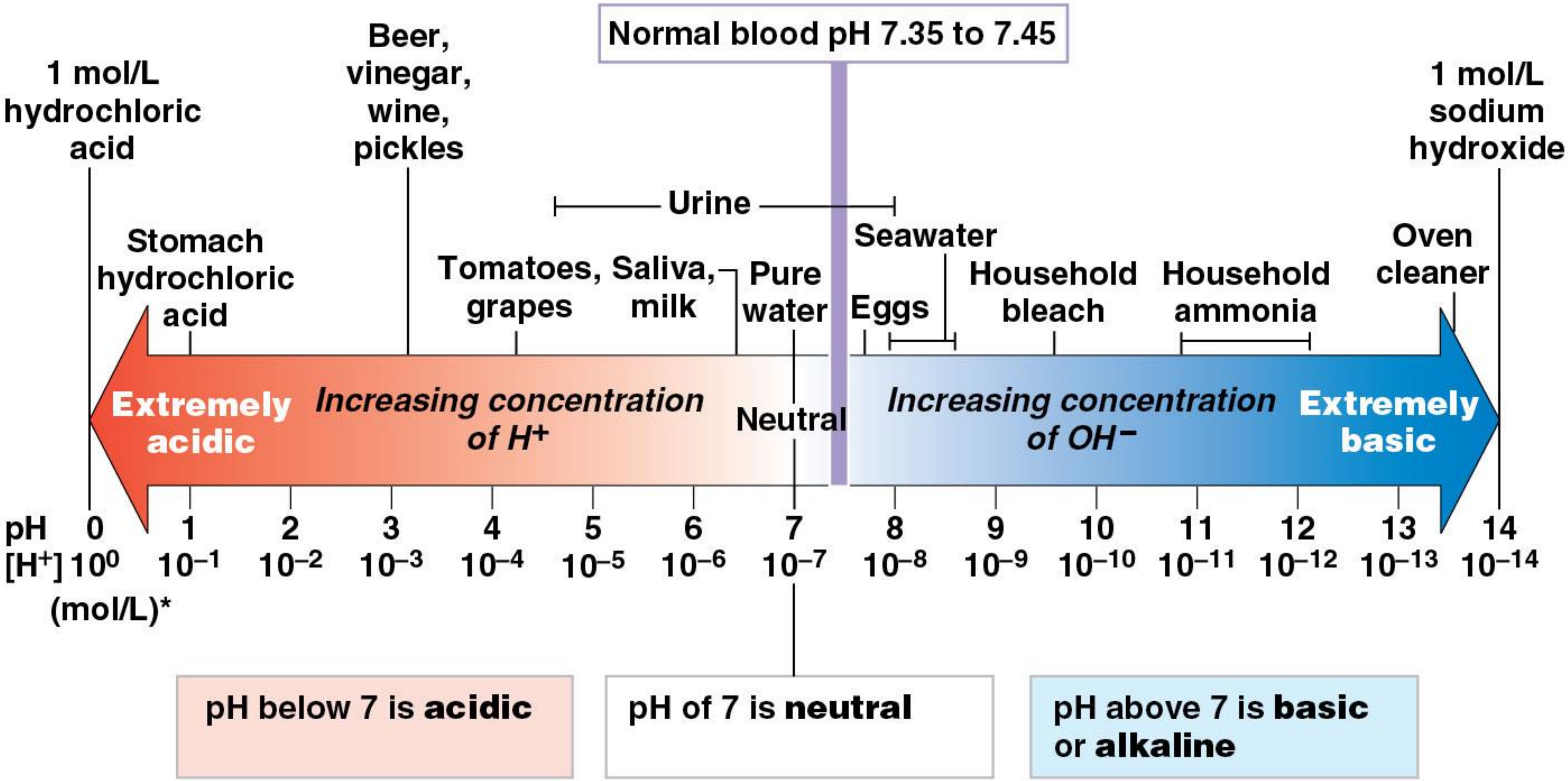
- **Hydrogen ion** (H^+)
  - Hydrogen atom that has lost electron
  - Extremely reactive in solution
  - In large numbers, can break chemical bonds and disrupt cell and tissue function
  - Concentration in body regulated precisely
- **Hydroxide ion** (OH^-)
  - Produced when water dissociates (along with H^+)

Module 2.12: pH

pH

- Measure of H^+ concentration in body fluids (negative logarithm in mol/L)
- Ranges from 0 to 14
  - **Acidic**: below 7
    - Contains more H^+ than OH^-
  - **Neutral**: equal to 7
    - Contains equal numbers of H^+ and OH^-
  - **Alkaline (basic)**: above 7
    - Contains more OH^- than H^+
- Change in one unit is tenfold change in H^+ ion concentration

pH scale


Normal blood pH 7.35 to 7.45
1 mol/L hydrochloric acid
Beer, vinegar, wine, pickles
1 mol/L sodium hydroxide
Urine
Stomach hydrochloric acid
Tomatoes, grapes
Saliva, milk
Pure water
Seawater
Eggs
Household bleach
Household ammonia
Oven cleaner
Extremely acidic
Increasing concentration of H+
Neutral
Increasing concentration of OH−
Extremely basic
pH 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
[H+] (mol/L)* 10^0 10^−1 10^−2 10^−3 10^−4 10^−5 10^−6 10^−7 10^−8 10^−9 10^−10 10^−11 10^−12 10^−13 10^−14
pH below 7 is acidic
pH of 7 is neutral
pH above 7 is basic or alkaline

Module 2.12: pH

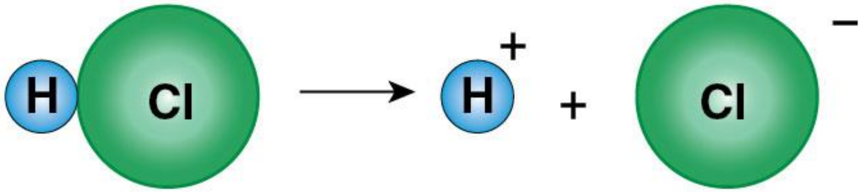
Normal pH of blood is 7.35–7.45

- Outside this range damages cells and tissues by:
  - Breaking chemical bonds
  - Changing shapes of proteins
  - Altering cellular functions
- **Acidosis** = below 7.35
  - pH below 7.0 causes coma
- **Alkalosis** = above 7.45
  - pH above 7.8 causes uncontrollable, sustained skeletal muscle contractions

Module 2.12: pH

Acid

- Solute that dissociates and releases hydrogen ions
- Often referred to as proton donors
  - After losing an electron, a hydrogen ion consists solely of a proton
- Strong acids dissociate completely
  - *Example:* **hydrochloric acid** (HCl)
    - $HCl \rightarrow H^+ + Cl^-$

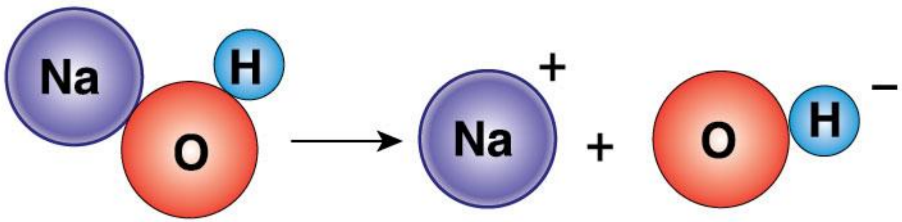


Module 2.12: pH

Base

- Solute that removes hydrogen ions from solution
- Proton acceptor
- May release a hydroxide ion
- Strong bases dissociate completely
  - *Example:* **sodium hydroxide** (NaOH)
    - $NaOH \rightarrow Na^+ + OH^-$

$$\mathbf{NaOH \longrightarrow Na^{+} + OH^{-}}$$

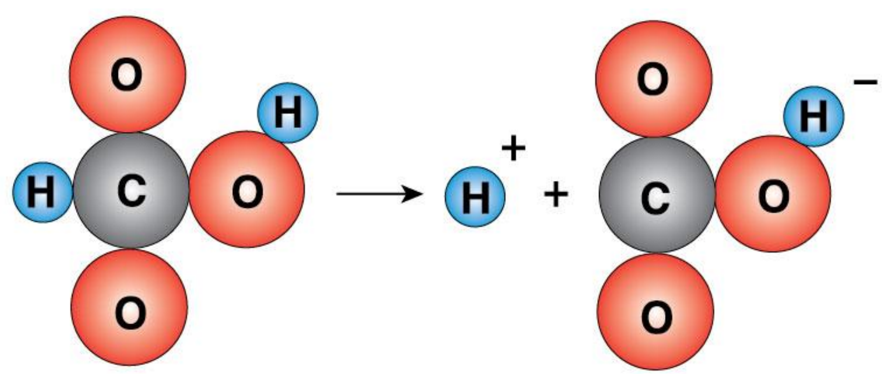


Module 2.12: pH

Weak acids and bases

- Fail to dissociate completely
- Have less of an impact on pH than strong acids and bases
- *Example:* **carbonic acid** (H_2CO_3)
  - $H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
  - In body fluids, carbonic acid reversibly dissociates to hydrogen ion and **bicarbonate ion**

$$\boxed{H_2CO_3 \rightleftharpoons H^+ + HCO_3^-}$$

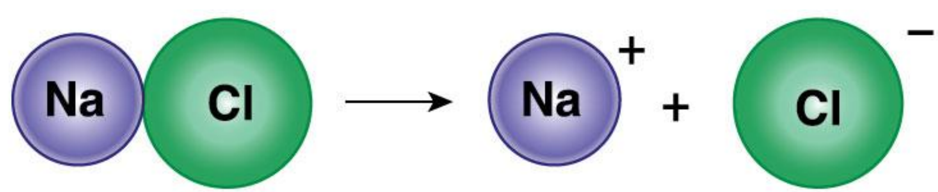


Module 2.12: pH

Salt

- Inorganic compound composed of any cation (except hydrogen) and any anion (except hydroxide)
- Held together by ionic bonds
- Many dissociate completely in water, releasing cations and anions
- *Example:* NaCl
  - $NaCl \rightarrow Na^+ + Cl^-$

$$\mathbf{NaCl \longrightarrow Na^+ + Cl^-}$$



Module 2.12: pH

Buffers

- Compounds that stabilize the pH of a solution by removing or replacing hydrogen ions
- Help to maintain normal pH of body fluids

Buffer systems

- Help maintain pH within normal limits
- Usually involve a weak acid and its related salt
- *Examples:*
  - Carbonic acid (H_2CO_3)
  - Sodium bicarbonate ($NaHCO_3$)

Module 2.12: Review

A. Define *pH*.

B. A hydrogen ion is the same as what subatomic particle?

C. Explain the differences among an acid, a base, and a salt.

D. What is the relationship between buffers and pH in physiological systems?

Learning Outcome: Discuss the importance of pH and the role of buffers in body fluids.

Section 4: Organic Compounds

Learning Outcomes

2.13 Describe the common elements of organic compounds and how functional groups modify the properties of organic compounds.

2.14 Discuss the structures and functions of carbohydrates.

2.15 Discuss the structures and functions of lipids.

2.16 Discuss the structures and diverse functions of eicosanoids, steroids, phospholipids, and glycolipids.

Learning Outcomes (continued)

2.17 Discuss protein structure and the essential functions of proteins within the body.

2.18 Explain how enzymes function within the body.

2.19 Discuss the structure and function of high-energy compounds.

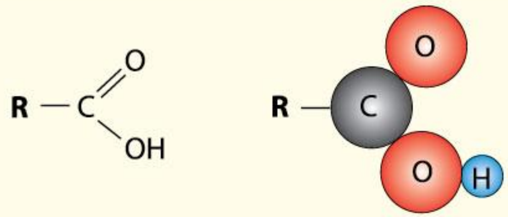
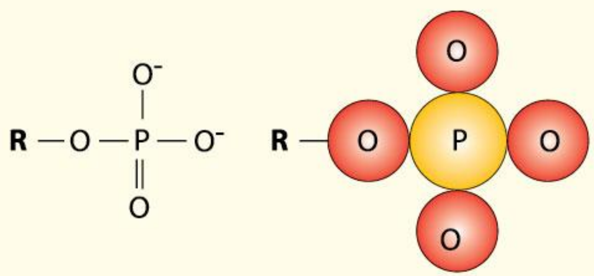
2.20 Compare and contrast the structures and functions of DNA and RNA.

Module 2.13: All organic compounds contain carbon and hydrogen atoms

Organic compounds

- Always contain carbon and hydrogen and generally oxygen
- Many are long chains of carbon linked with covalent bonds
- Many are soluble in water
- **Functional groups**
  - Attached groupings of atoms that occur commonly in many organic molecules
  - Influence the properties of the overall molecule
- Many allow cells to transfer and capture energy as **high-energy compounds**

Important Functional Groups of Organic Compounds

Functional Group	Structural Formula *	Importance	Examples
Amino group, $-NH_2$		Acts as a base, accepting H^+, depending on pH; can form bonds with other molecules	• Amino acids
Carboxyl group, $-COOH$		Acts as an acid, releasing H^+ to become $R{-}COO^-$	• Fatty acids • Amino acids
Hydroxyl group, $-OH$		May link molecules through dehydration synthesis; hydrogen bonding between hydroxyl groups and water molecules affects solubility	• Carbohydrates • Fatty acids • Amino acids • Alcohols
Phosphate group, $-PO_4^{2-}$		May link other molecules to form larger structures; may store energy	• Phospholipids • Nucleic acids • High-energy compounds

* A structural formula shows the covalent bonds within a molecule or functional group. For example, a single covalent bond is represented by a single line (—), a double bond by two parallel lines (=). Although not shown here, a triple bond is represented by three parallel lines (≡). **R** represents the organic molecule to which a functional group is attached.

Module 2.13: Review

A. List the elements that make up organic compounds.
B. What is a functional group?
C. Identify the important functional groups of organic compounds.
D. Describe the functional groups that are considered acidic or basic.

Learning Outcome: Describe the common elements of organic compounds and how functional groups modify the properties of organic compounds.

Module 2.14: Carbohydrates contain carbon, hydrogen, and oxygen, usually in a 1:2:1 ratio

Carbohydrates

- Organic molecules containing carbon, hydrogen, and oxygen in ratio near 1:2:1
- *Examples:* sugars and starches
- Roughly 1.5 percent of total body weight
- Most important as energy sources

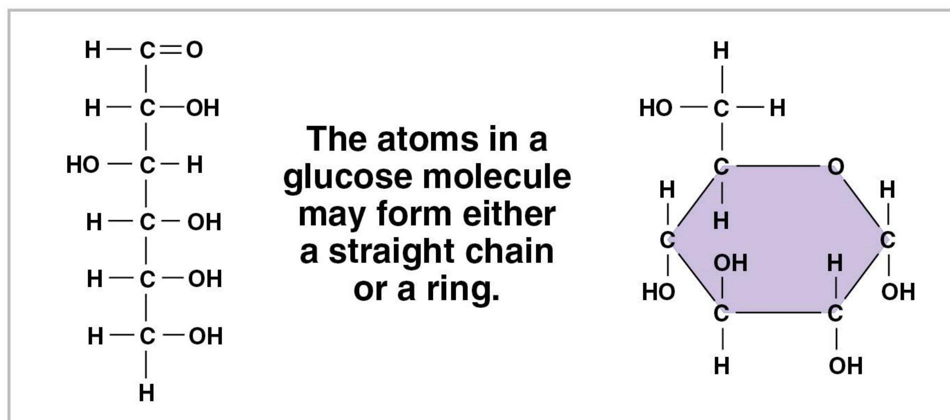
Carbohydrates in the Body

Structural Class	Examples	Primary Function	Remarks
Monosaccharides (simple sugars)	Glucose, fructose	Energy source	Manufactured in the body and obtained from food; distributed in body fluids
Disaccharides	Sucrose, lactose, maltose	Energy source	Sucrose is table sugar, lactose is in milk, and maltose is malt sugar; all must be broken down to monosaccharides before absorption
Polysaccharides	Glycogen	Glucose storage	Glycogen is in animal cells; other starches and cellulose are within or around plant cells

Module 2.14: Carbohydrates

Types of carbohydrates

1. **Monosaccharide** (*mono-*, single + *sakcharon*, sugar)—simple sugar
   - Contains three to seven carbon atoms
     - Triose (three-carbon)
     - Tetrose (four-carbon)
     - Pentose (five-carbon)
     - Hexose (six-carbon) (**glucose**, most important fuel in body)
     - Heptose (seven-carbon)

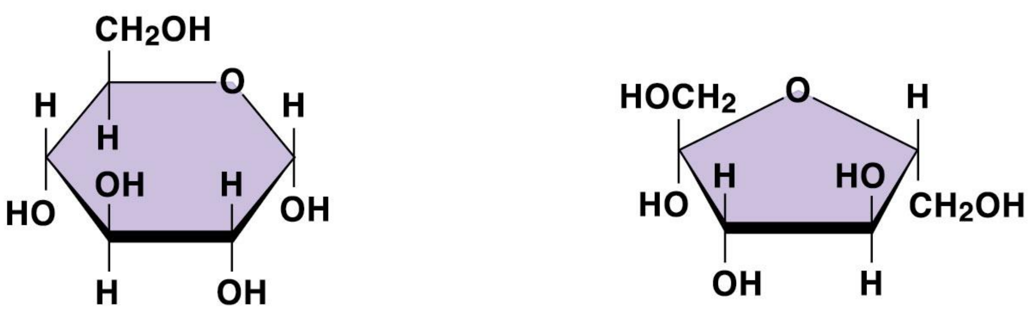


The atoms in a glucose molecule may form either a straight chain or a ring.

Module 2.14: Carbohydrates

Isomers—Molecules with the same molecular formula but different structures

- Can be important in molecular function
- *Example:* glucose and **fructose**
  - Both have molecular formula of $C_6H_{12}O_6$
  - Structures are different



Glucose

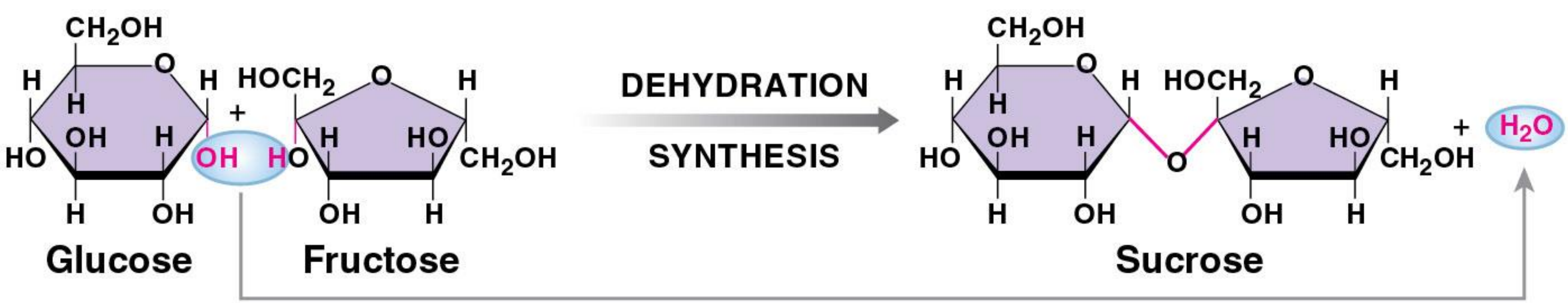
Fructose

Fructose has the same chemical formula as glucose but a different arrangement of atoms.

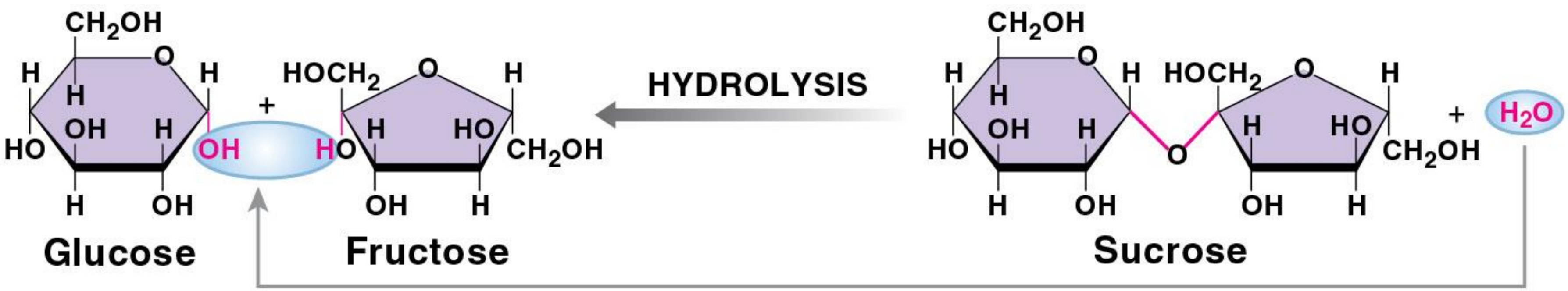
Module 2.14: Carbohydrates

Types of carbohydrates (continued)

2. **Disaccharide** (*di-*, two)
   - Two monosaccharides joined
   - *Example:* **sucrose**
   - Dehydration synthesis creates disaccharides
   - Very soluble in water
   - Hydrolysis breaks them down to monosaccharides



Hydrolysis breaks dissacharides down to monosaccharides

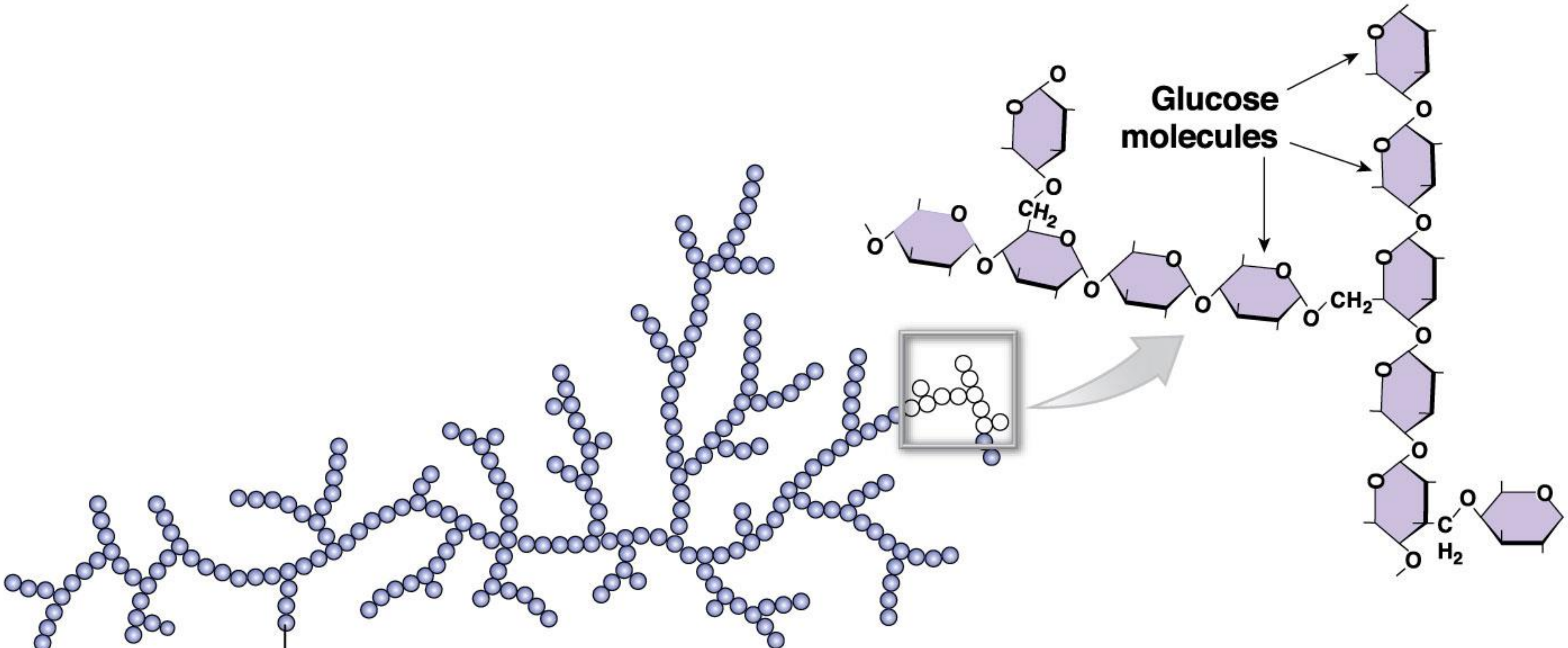


Module 2.14: Carbohydrates

Types of carbohydrates

3. **Polysaccharides** (*poly-*, many)
   - Complex carbohydrates formed from multiple disaccharides and/or monosaccharides
   - *Examples:*
     - **Starches**
       - Formed by plants from glucose
       - Broken down into monosaccharides by digestive system
       - Major dietary energy source (potatoes and grains)
     - **Glycogen**
       - Animal starch (formed by animals from glucose)
       - Muscle cells make and store glycogen
       - Broken down when high demand for glucose

Polysaccharides



Glycogen has many side branches consisting of chains of glucose molecules.

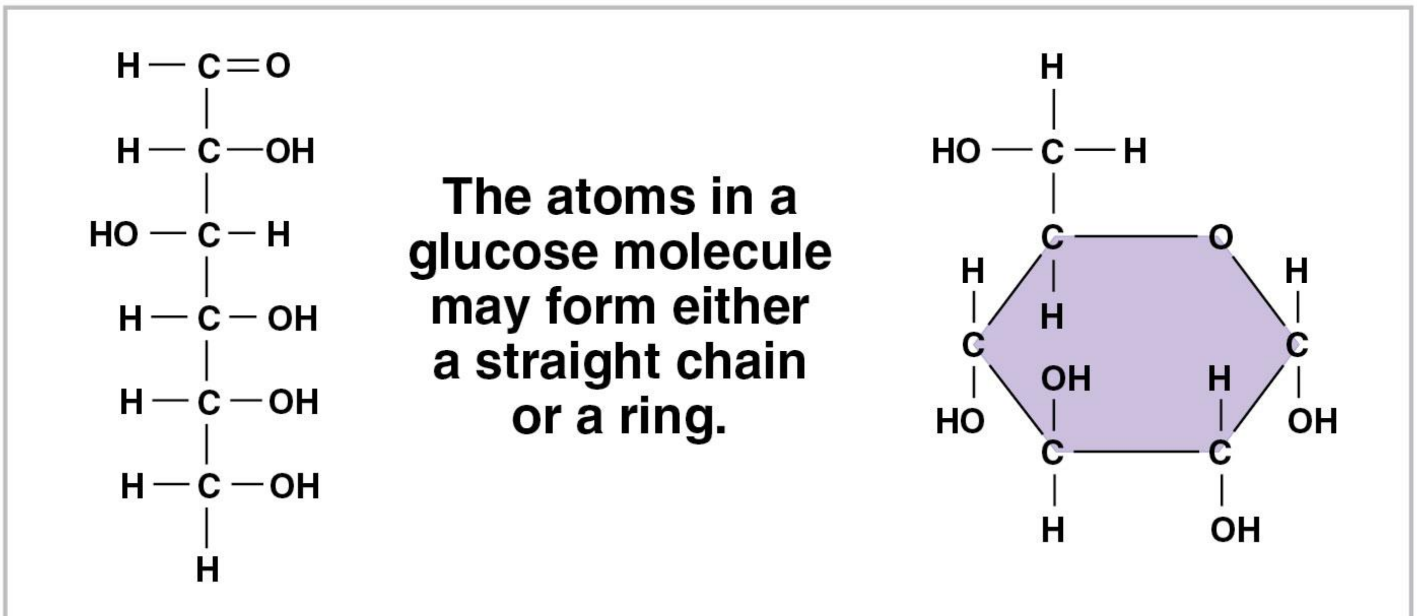
Carbohydrates in the Body

Structural Class	Examples	Primary Function	Remarks
Monosaccharides (simple sugars)	Glucose, fructose	Energy source	Manufactured in the body and obtained from food; distributed in body fluids
Disaccharides	Sucrose, lactose, maltose	Energy source	Sucrose is table sugar, lactose is in milk, and maltose is malt sugar; all must be broken down to monosaccharides before absorption
Polysaccharides	Glycogen	Glucose storage	Glycogen is in animal cells; other starches and cellulose are within or around plant cells

Module 2.14: Review

A. What is the most important function of carbohydrates?

B. Which of the structural representations of glucose shown below is more common in the body?



Module 2.14: Review

C. List the three structural classes of carbohydrates, and give an example of each.

D. Predict the reactants and the type of chemical reaction involved when muscle cells make and store glycogen.

Learning Outcome: Discuss the structures and functions of carbohydrates.

Module 2.15: Lipids often have a carbon-to-hydrogen ratio of 1:2

Lipids (*lipos*, fat)

- Contain carbon, hydrogen, and oxygen
- Carbon to hydrogen ratio is near 1:2
- Much less oxygen compared to carbohydrates with similar number of carbon atoms
- May contain small quantities of phosphorus, nitrogen, or sulfur
- *Examples:* fats, oils, waxes
- Most are insoluble in water
  - Special transport mechanisms for them in the blood

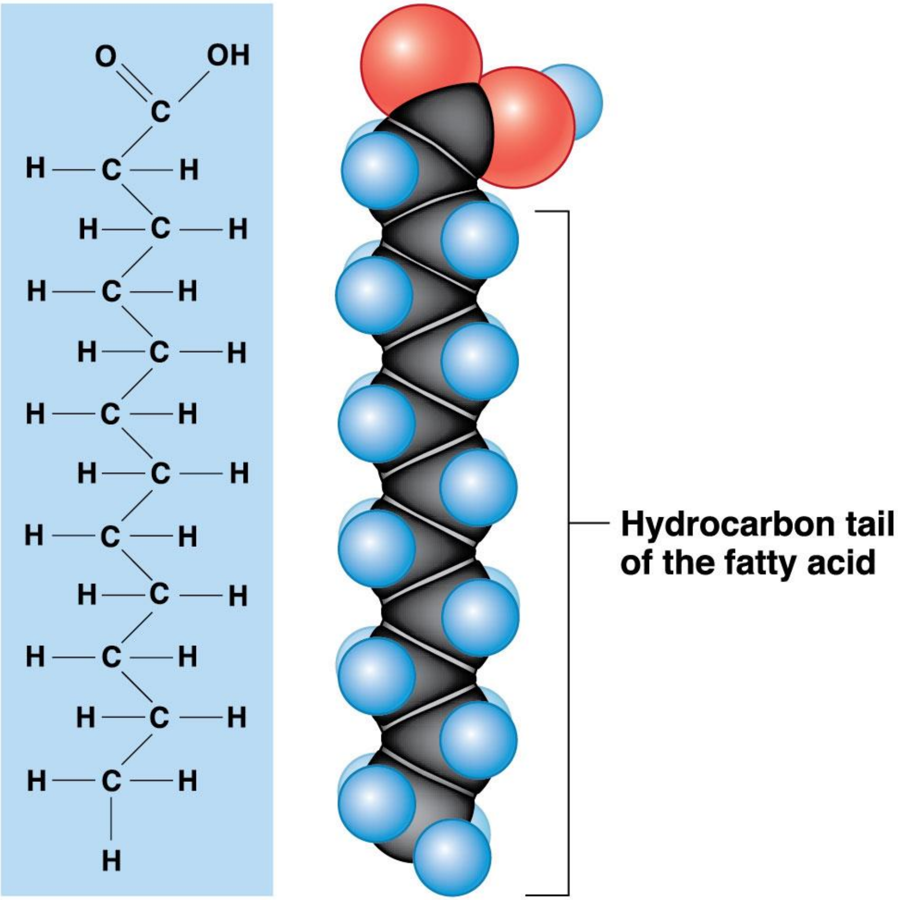
Representative Lipids in the Body

Lipid Type	Examples	Primary Functions	Remarks
Fatty acids	Lauric acid	Energy sources	Absorbed from food or synthesized in cells; transported in the blood
Glycerides	Monoglycerides, diglycerides, triglycerides	Energy sources, energy storage, insulation, and physical protection	Stored in fat deposits; must be broken down to fatty acids and glycerol before they can be used as an energy source
Eicosanoids (see Module 2.16)	Prostaglandins, leukotrienes	Chemical messengers coordinating local cellular activities	Prostaglandins are produced in most body tissues
Steroids (see Module 2.16)	Cholesterol	Structural components of cell membranes, hormones, digestive secretions in bile	All steroids have the same carbon ring framework
Phospholipids, glycolipids (see Module 2.16)	Lecithin (a phospholipid)	Structural components of plasma membranes	Derived from fatty acids and nonlipid components

Module 2.15: Lipids

Fatty acids

- Long carbon chains with attached hydrogen atoms
- Two ends
  1. Head
     – Has **carboxyl group** (–COOH)
     – Hydrophilic
  2. Tail
     – Hydrophobic
     – The longer the tail, the lower the solubility



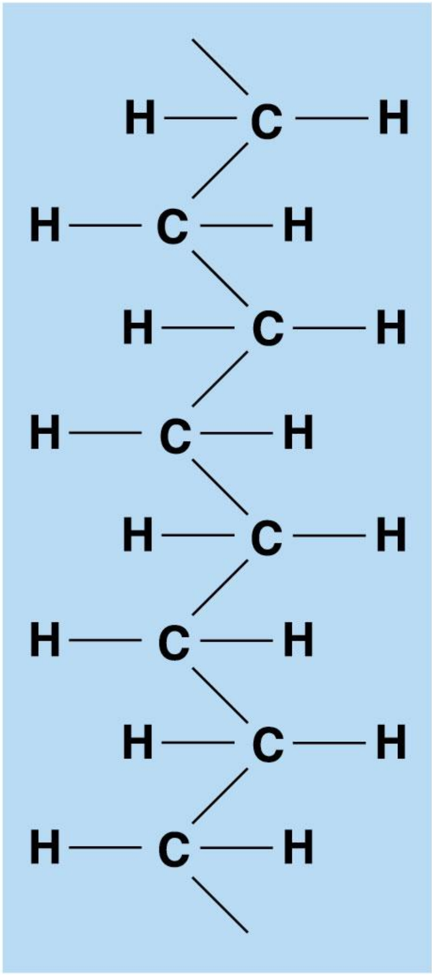
Lauric acid ($C_{12}H_{24}O_2$)

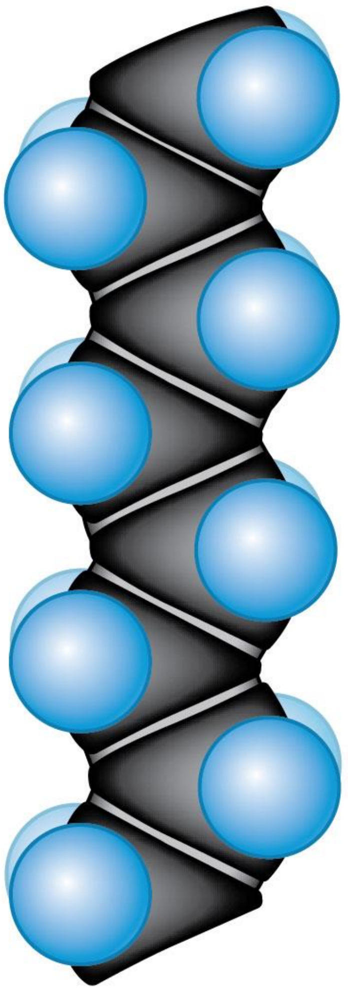
Module 2.15: Lipids

Fatty acids
(continued)

Two types

1. **Saturated fatty acid**
   - Each carbon in the tail has four attached hydrogens

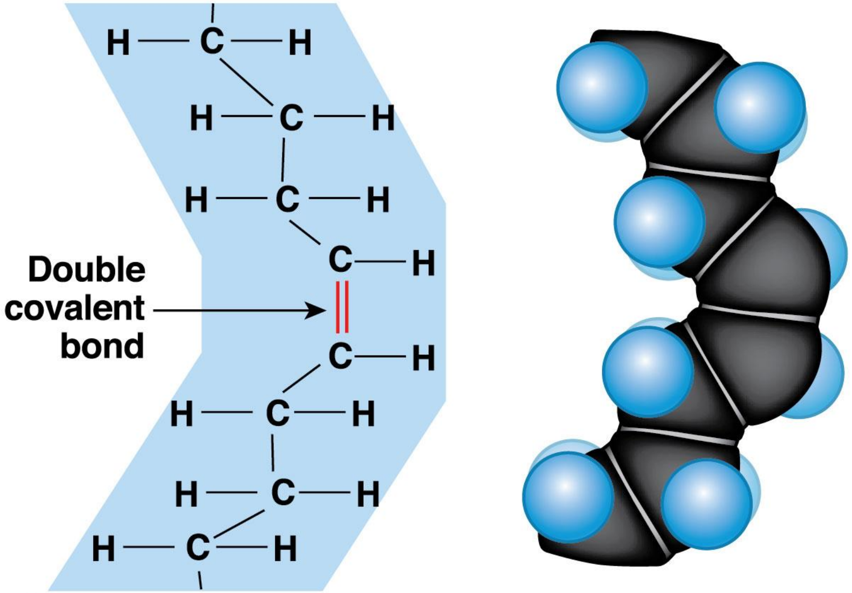




Module 2.15: Lipids

Fatty acids

2. **Unsaturated fatty acid**
    - Contains double bonds in the tail
        - One double bond =
        - monounsaturated
        - >1 double bond =
        - polyunsaturated
    - Has fewer attached hydrogens



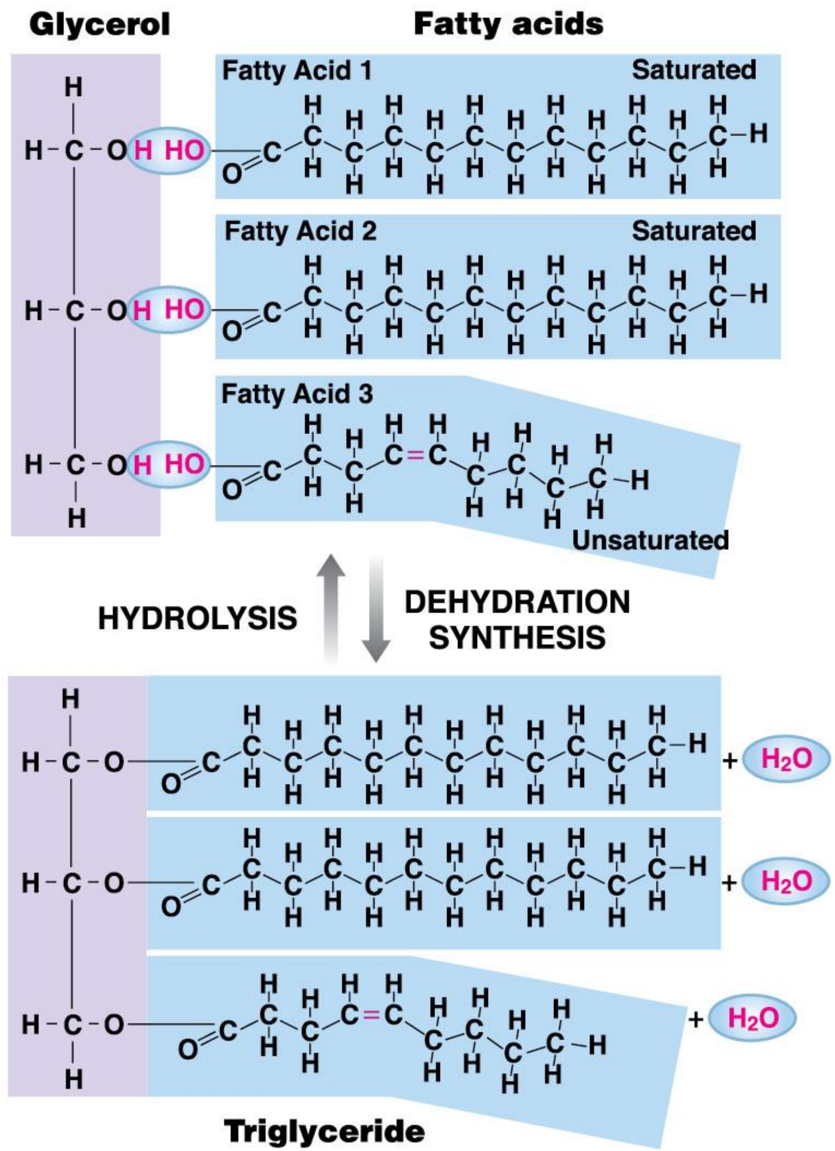
- The double bonds change the shape of the tail
- Changes the way the body metabolizes the fatty acid

Module 2.15: Lipids

Glycerides

- Fatty acid chains attached to a **glycerol** molecule
- Three types formed through dehydration synthesis
  1. **Monoglyceride** (glycerol + one fatty acid)
  2. **Diglyceride** (glycerol + two fatty acids)
  3. **Triglyceride** (glycerol + three fatty acids)
     – Also known as triacylglycerols or neutral fats
- Hydrolysis breaks glycerides into fatty acids and glycerol

Dehydration synthesis produces glycerides and hydrolysis breaks them down



Module 2.15: Lipids

Lipids in the body

- Essential components of all cells
- Important as energy reserves
- Provide twice as much energy as carbohydrates
- Normally account for 12–18 percent of total body weight for men and 18–24 percent for women
- Humans must obtain some fatty acids from the diet

Module 2.15: Review

A. Describe lipids in terms of their elemental composition and solubility in water.
B. List examples of representative lipids in the body.
C. Describe the structures of saturated and unsaturated fatty acids.
D. In the hydrolysis of a triglyceride, what are the reactants and the products?
E. Summarize the functions of lipids in the body.

Learning Outcome: Discuss the structures and functions of lipids.

Module 2.16: Eicosanoids, steroids, phospholipids, and glycolipids have diverse functions

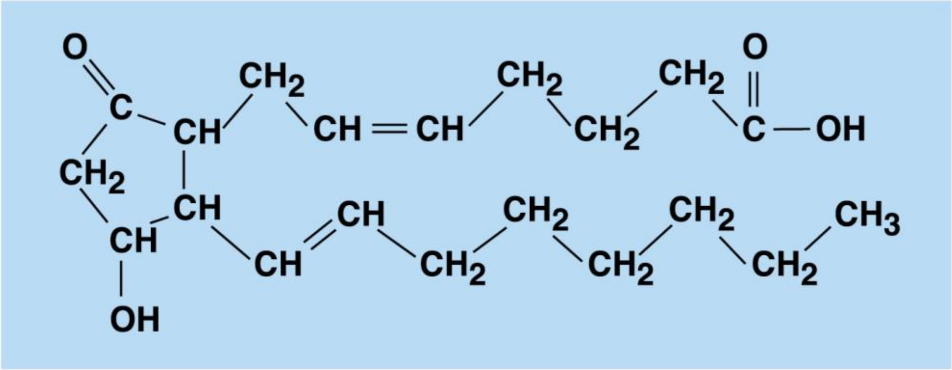
Some functions of lipids

- Chemical messengers and components of cellular structures
- **Structural lipids** help form and maintain outer cell membrane and intracellular membranes
  - Allow separation of different aqueous solutions

Module 2.16: Diverse functions of lipids

Eicosanoids: Lipids derived from arachidonic acid

- Lipids derived from arachidonic acid
- *Examples:*
  - **Leukotrienes**
    - Produced by cells in response to injury or disease
  - **Prostaglandins**
    - Released by cells to coordinate local cellular activities
    - Extremely powerful even in minute quantities
    - Release by damaged tissue stimulates nerve endings, producing sensation of pain



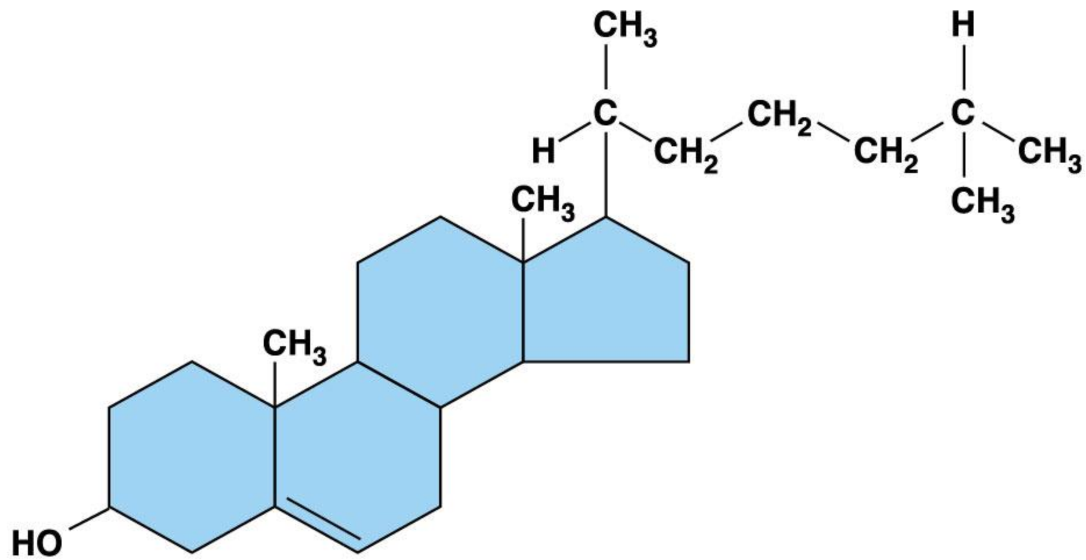
Module 2.16: Diverse functions of lipids

Steroids

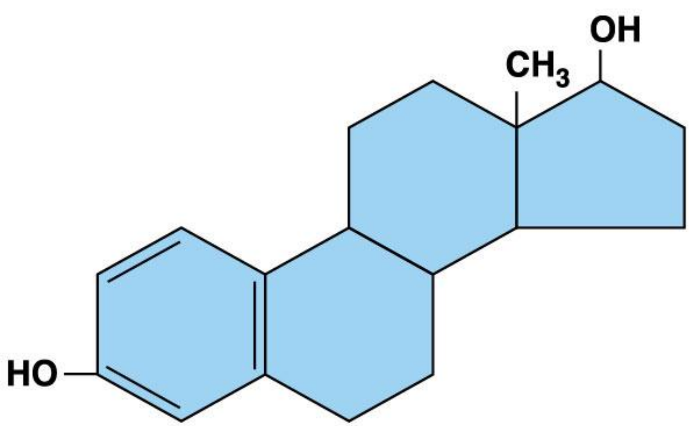
- Large molecules with four carbon rings
- Differ in attached functional groups
- *Examples:*
  - **Cholesterol** (*chole-*, bile + *steros*, solid)
    - Functions to maintain plasma membranes
    - Also needed for cell growth and division
  - Sex hormones (estrogen and testosterone)
    - Regulation of sexual and other metabolic functions

Steroids

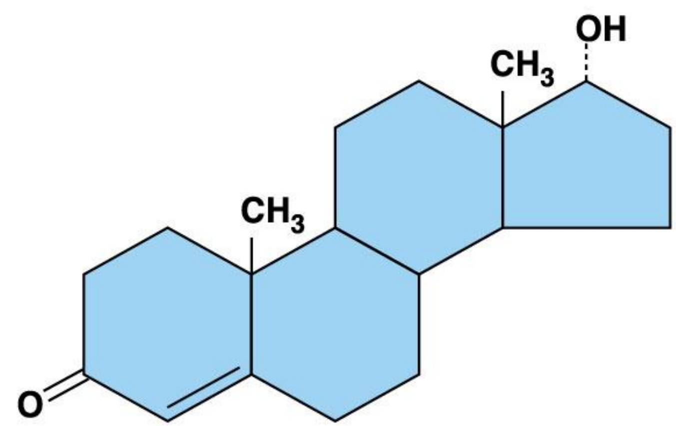
Cholesterol



Estrogen



Testosterone

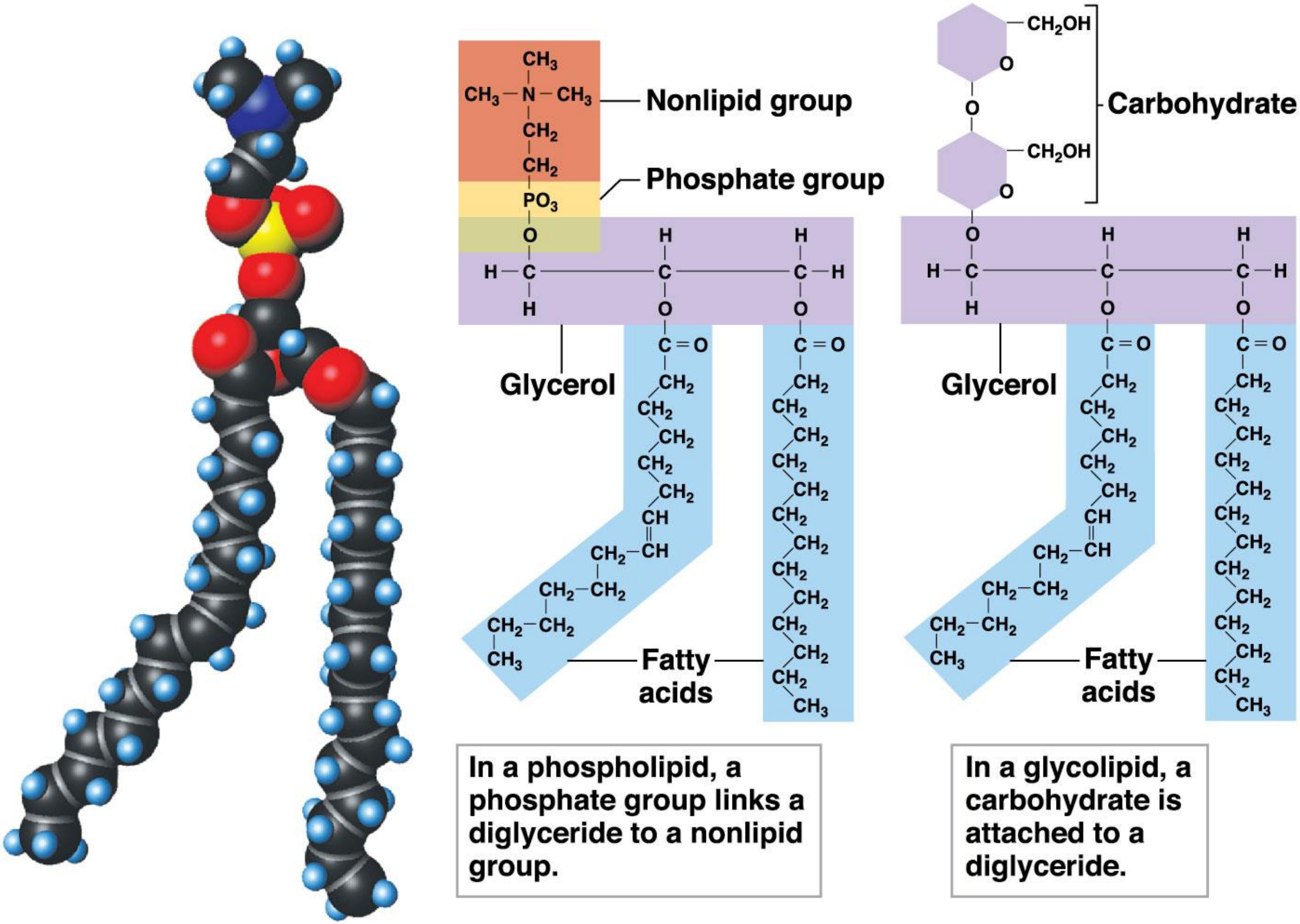


Module 2.16: Diverse functions of lipids

Phospholipids and glycolipids

- Both are diglycerides
- **Phospholipid**
  - Phosphate linking a diglyceride to a nonlipid group
- **Glycolipid**
  - Carbohydrate attached to a diglyceride

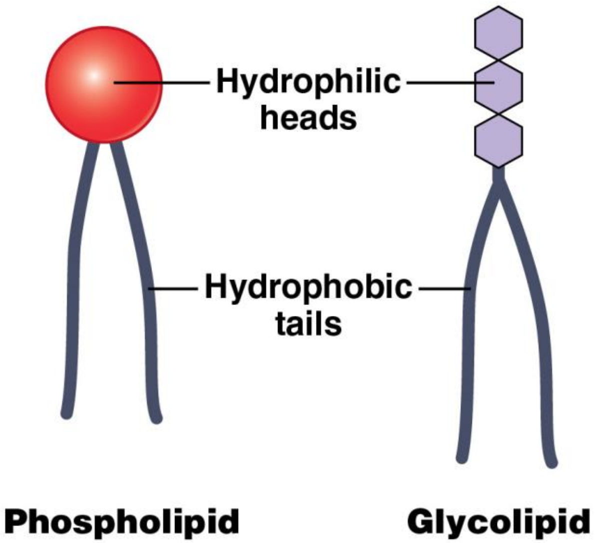
Phospholipids and glycolipids

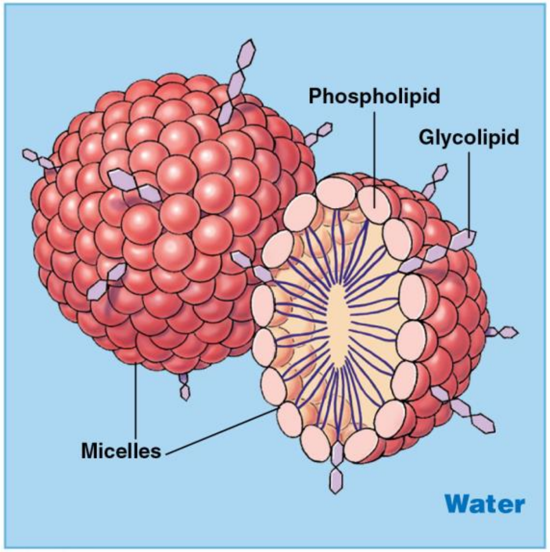


Module 2.16: Diverse functions of lipids

Phospholipids and glycolipids (continued)

- Structurally related
- Can be synthesized by cells primarily from fatty acids
- Like fatty acids
  - Tails are hydrophobic
  - Heads are hydrophilic
- In water, can form large droplets (**micelles**)





Module 2.16: Review

A. Describe the structure and role of prostaglandins.
B. Why is cholesterol necessary in the body?
C. Describe the orientations of phospholipids and glycolipids when they form a micelle.
D. What do cholesterol, phospholipids, and glycolipids have in common?

Learning Outcome: Discuss the structures and diverse functions of eicosanoids, steroids, phospholipids, and glycolipids.

Module 2.17: Proteins are formed from amino acids

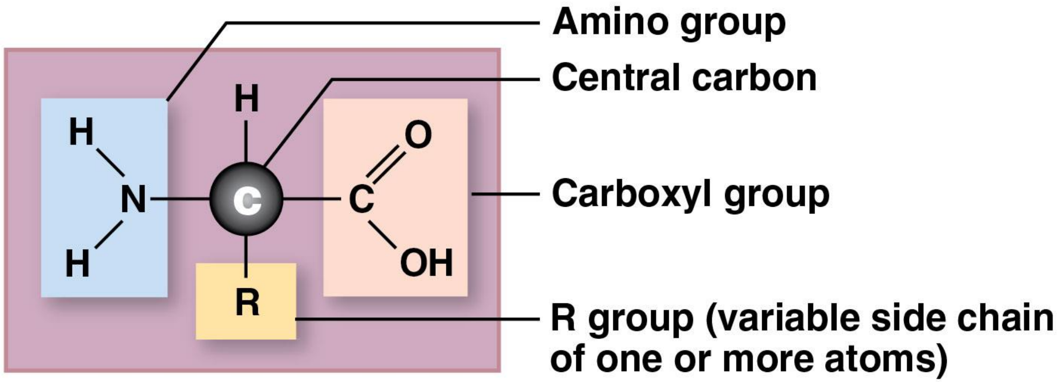
Proteins

- Most abundant organic molecule in the body
- In many ways, are most important
- Normally account for 20 percent of total body weight
- Contain carbon, hydrogen, oxygen, and nitrogen
  - Possibly sulfur and phosphorus as well
- Consist of long chains of **amino acids**
  - 20 different amino acids in the body
  - Typical protein contains 1000 amino acids
- Three-dimensional shape determines functional properties

Module 2.17: Proteins

Amino acids

- All have same structural components
  - Central carbon attached to four different groups
    1. Hydrogen atom
    2. Amino group
    3. Carboxyl group
    4. R group (variable side chain that gives amino acid chemical properties)
  - Molecule has both positive and negative charges, but net charge of zero

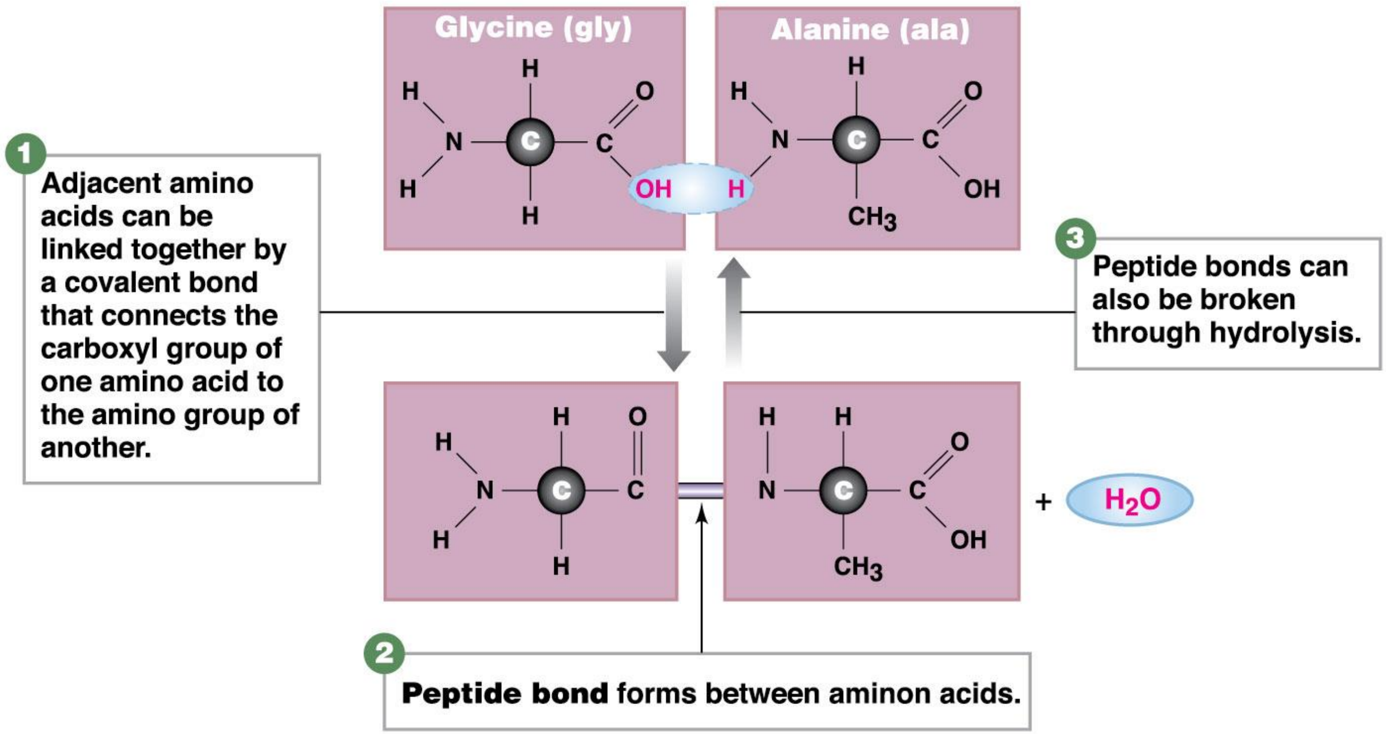


Module 2.17: Proteins

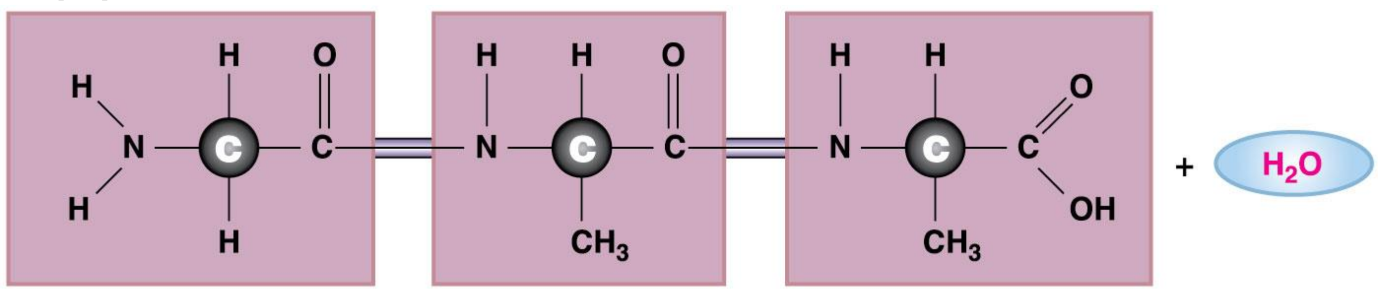
Peptides

- Amino acids linked through dehydration synthesis
- Covalent bond connects the carboxylic acid group of one amino acid to the amino group of another
  - This covalent bond is called a **peptide bond**
- **Dipeptide**
  - Two amino acids linked together
- **Polypeptides**
  - Three or more amino acids linked together
- Peptides of over 100 amino acids are called proteins

Formation of peptide bonds



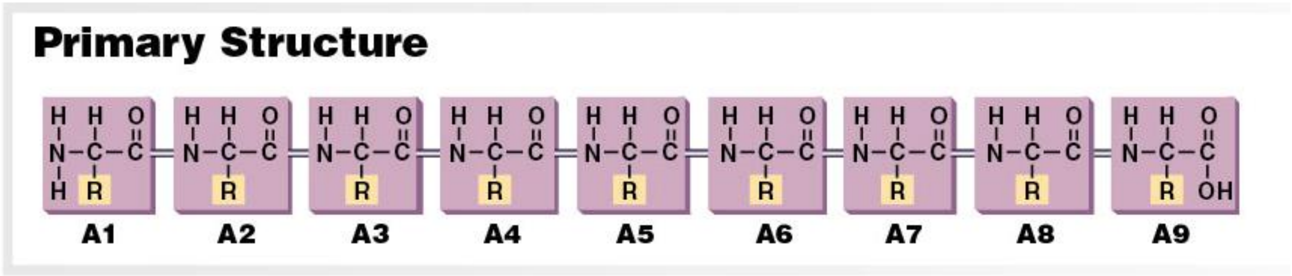
Tripeptide formation



Module 2.17: Proteins

Protein structure

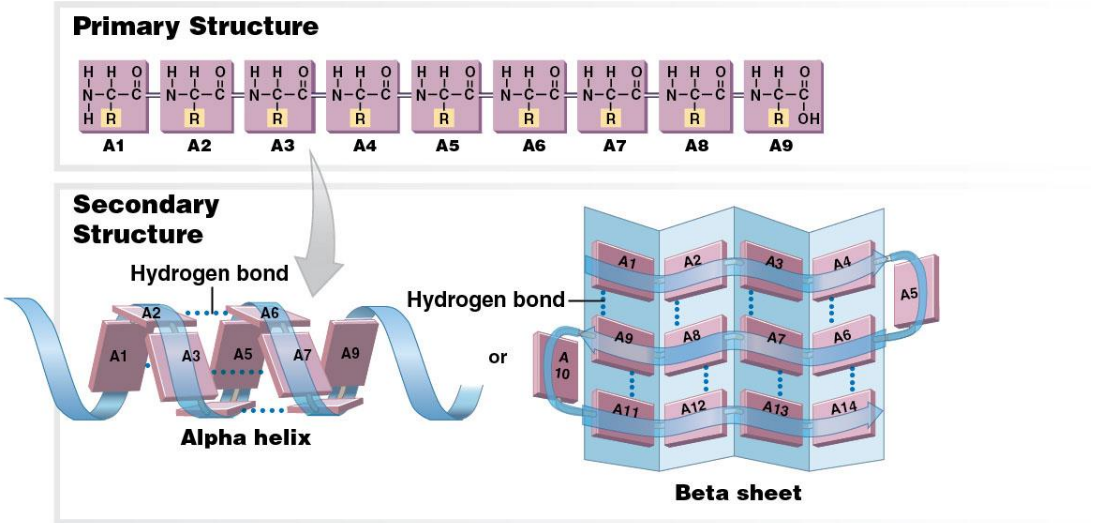
1. **Primary structure**—sequence of amino acids



Module 2.17: Proteins

Protein structure (continued)

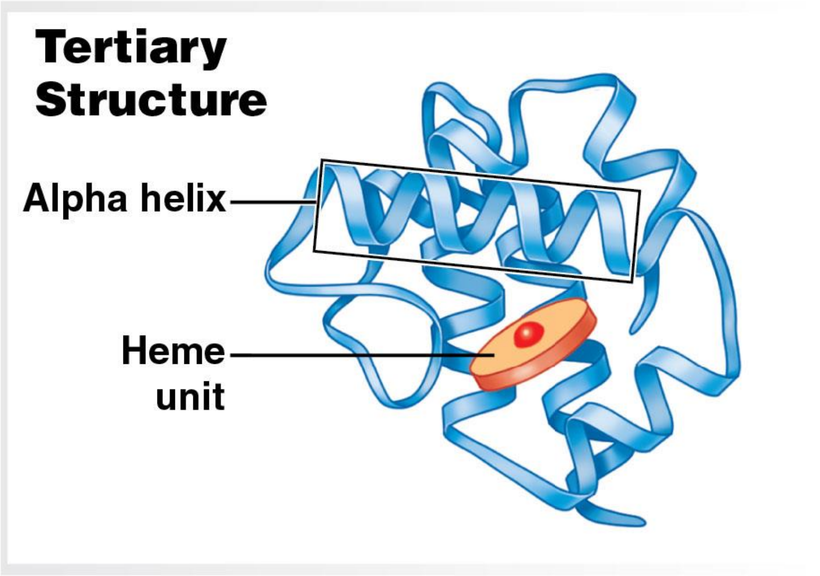
2. **Secondary structure**—results from bonds formed between atoms at different parts of the polypeptide chain
   – *Example:* hydrogen bonds
   - May create simple spiral (alpha-helix) or flat pleated sheet (beta sheet)



Module 2.17: Proteins

Protein structure (continued)

3. **Tertiary structure**—coiling and folding giving the protein a final 3-D shape
   - Usually from interactions of the protein and surrounding water molecules
   - Some contribution from interactions between R groups of amino acids in protein

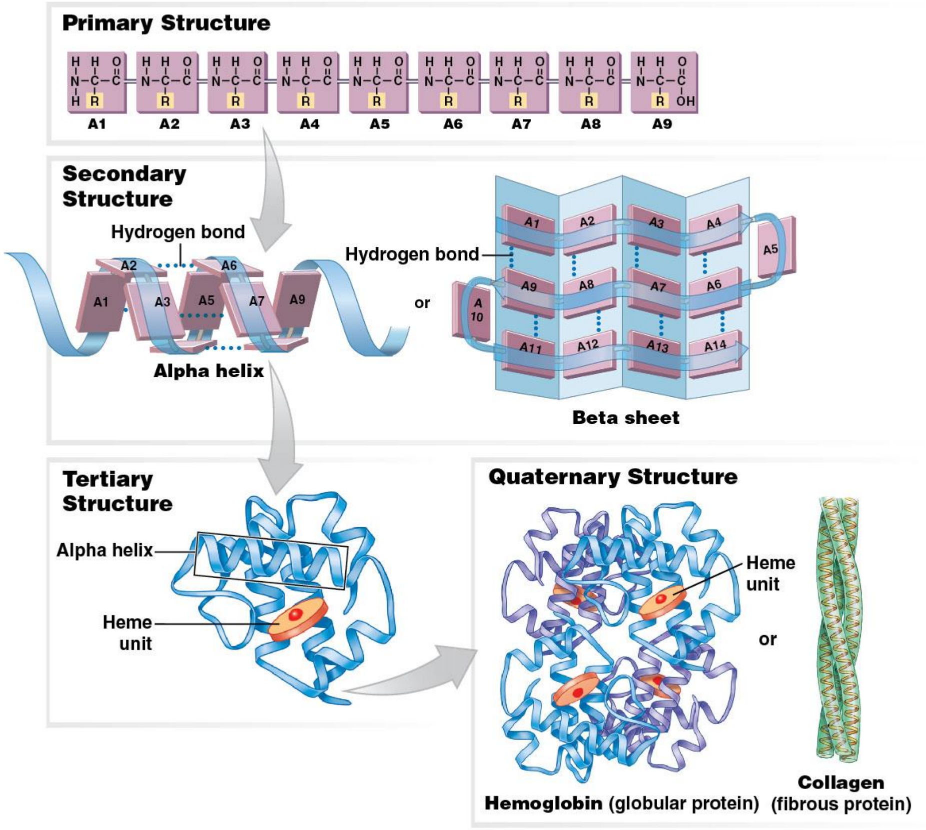


Module 2.17: Proteins

Protein structure
(continued)

Quaternary structure

- Results from interaction between multiple polypeptide chains forming a protein complex



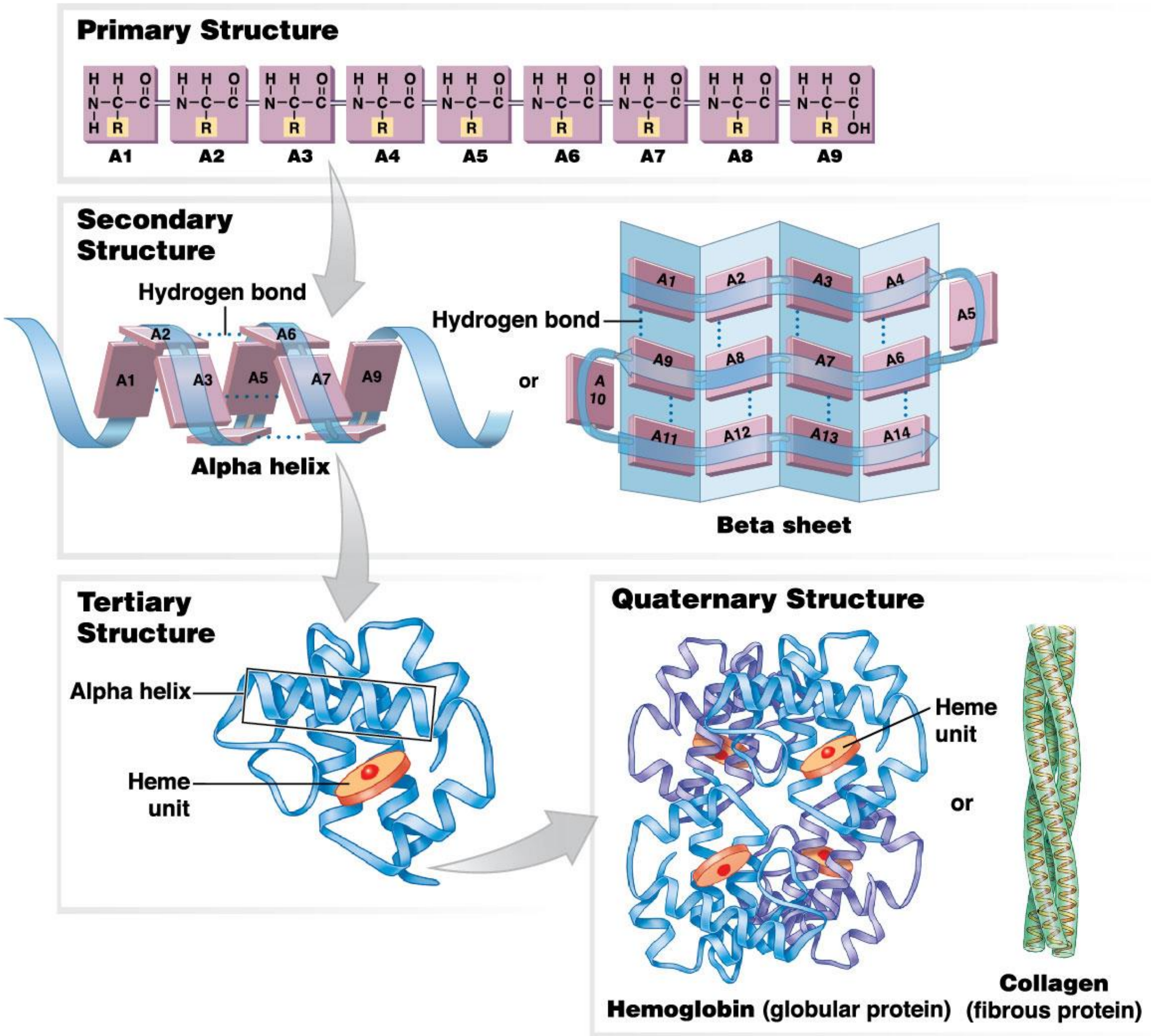
Module 2.17: Proteins

Protein structure (continued)

Quaternary structure (continued)

- *Examples:*
  - **Hemoglobin**
    - Contains four polypeptide subunits that form a globular protein
    - Binds oxygen in red blood cells
  - **Collagen**
    - Three linear subunits intertwine, forming a fibrous protein
    - Fibrous proteins that give strength to tissues

Polypeptides have four levels of structural complexity



Module 2.17: Proteins

Denaturation

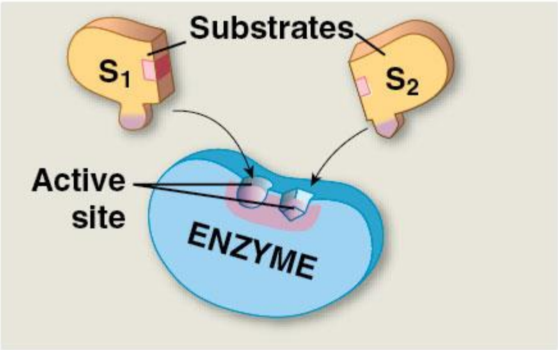
- Change in protein tertiary or quaternary structure
- Protein shape changes and function deteriorates
- Occurs under extreme conditions
  - Body temperature above 43ºC or 110ºF
- Fatal due to denaturation of structural proteins and enzymes
- Irreparable damage can occur to tissues and organs

Module 2.17: Review

A. Describe proteins.
B. What kind of bond forms during the dehydration synthesis of two amino acids, and which functional groups are involved?
C. Why does boiling a protein affect its functional properties?

Learning Outcome: Discuss protein structure and the essential functions of proteins within the body.

Module 2.18: Enzymes are proteins with important regulatory functions



Enzymes facilitate most everything that occurs inside the body

- **Active site**
  - Specific region of an enzyme where substrates must bind
  - Site shape determined by tertiary or quaternary structure of enzyme
- **Substrates**
  - Reactants in enzymatic reactions
  - Interactions among substrates yield specific products

Module 2.18: Enzymes are regulatory proteins

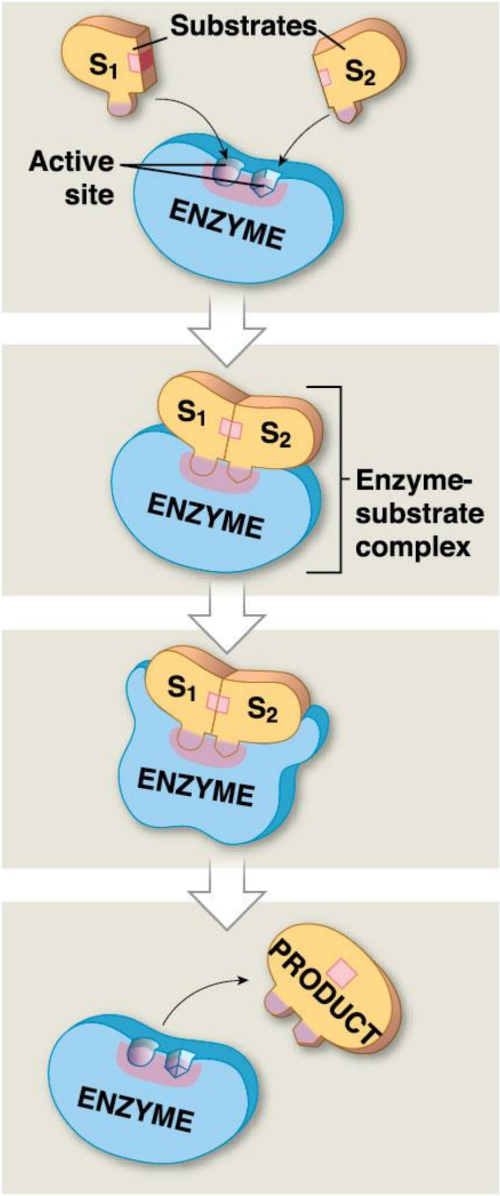
Structure of interacting molecules is very important in enzymatic reactions

- Substrate and enzyme fit in a “lock and key” fashion
- Each enzyme binds only to substrate with particular shape and charge
- Each enzyme catalyzes only one type of reaction
  - Characteristic called **specificity**

Module 2.18: Enzymes are regulatory proteins

Overall process

1. Substrate binds to active site on enzyme, forming **enzyme-substrate complex**
2. Substrate binding results in a temporary, reversible change in shape of enzyme
3. Completed product detaches from the active site
4. Enzyme is able to repeat process



Module 2.18: Enzymes are regulatory proteins

Control of reaction rates

- Multiple enzymes in each cell
- Each enzyme is active under its own set of conditions
- Enzyme activation or inactivation is important method of short-term control over reaction rates and pathways

Saturation limit

- Substrate concentration required to have maximum rate of reaction
- Every enzyme molecule is cycling through reaction sequence

Module 2.18: Review

A. What are the reactants in an enzymatic reaction called?

B. Relate an enzyme’s structure to its reaction specificity.

Learning Outcome: Explain how enzymes function within the body.

Module 2.19: High-energy compounds may store and transfer a portion of energy released during enzymatic reactions

High-energy compounds

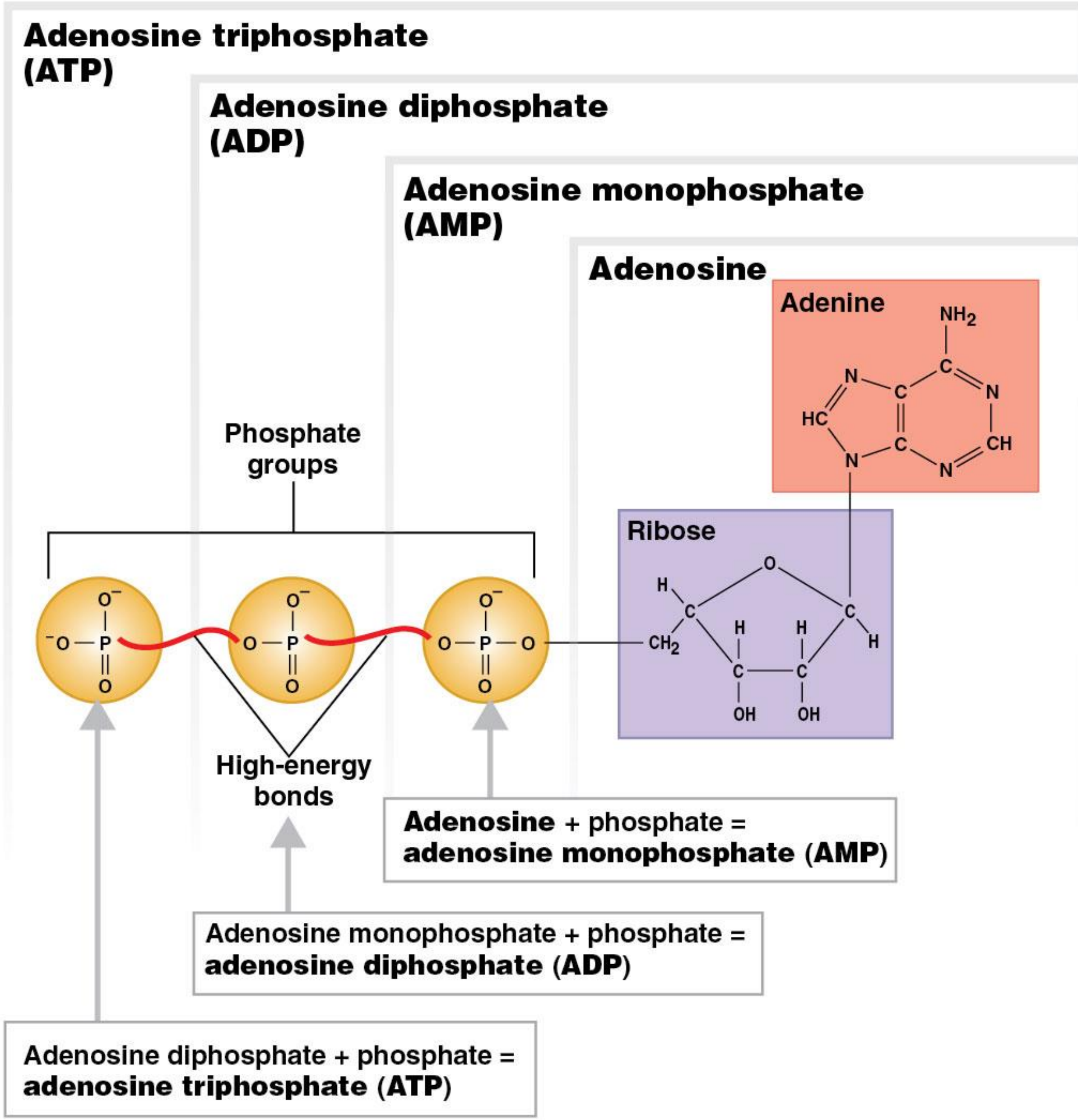
- Donate energy to enzymatic reactions to form products
- Contain **high-energy bonds**
  - Covalent bonds that release energy when broken
- **Adenosine triphosphate** (**ATP**)
  - Most common high-energy compound

Module 2.19: High-energy compounds

Formation of adenosine triphosphate (ATP)

- Begins with adenosine
  - Composed of adenine and a ribose
- **Adenosine monophosphate (AMP)**
  - Adenosine bound to a single phosphate
- **Adenosine diphosphate (ADP)**
  - Adenosine monophosphate with a second high-energy bond to a phosphate (total 2 phosphates)
- **Adenosine triphosphate (ATP)**
  - Adenosine diphosphate with yet another high-energy bond to a phosphate (total 3 phosphates)

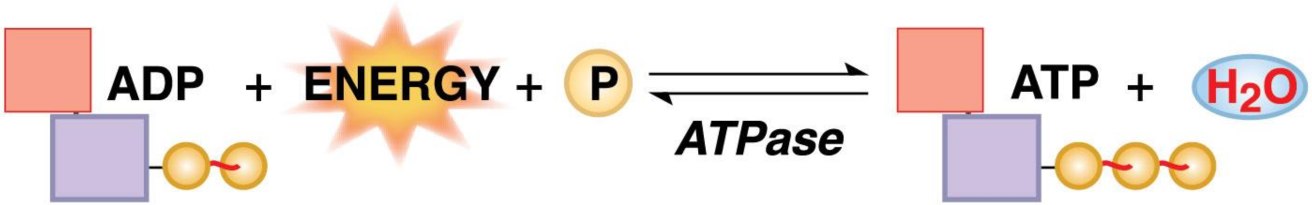
High-energy compounds



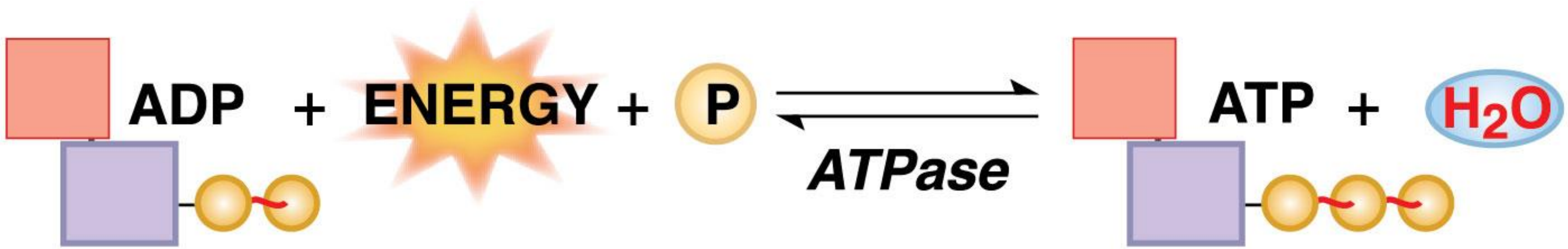
Module 2.19: High-Energy Compounds

Adenosine triphosphate (ATP) allows energy transfer

- Formation of ATP from ADP is reversible
  - Energy stored in ATP formation is released when ATP broken down to ADP
  - Allows cells to harness energy in one location and release it in another location
  - Provides energy for many vital body functions
    - *Examples:*
      - Contraction of muscles
      - Synthesis of proteins, carbohydrates, and lipids



Formation of ATP from ADP



Module 2.19: Review

A. Describe ATP.

B. Compare AMP with ADP.

C. Where do cells obtain the energy needed for their vital functions?

D. What are the products of ATP hydrolysis?

Learning Outcome: Discuss the structure and function of high-energy compounds.

Module 2.20: DNA and RNA are nucleic acids

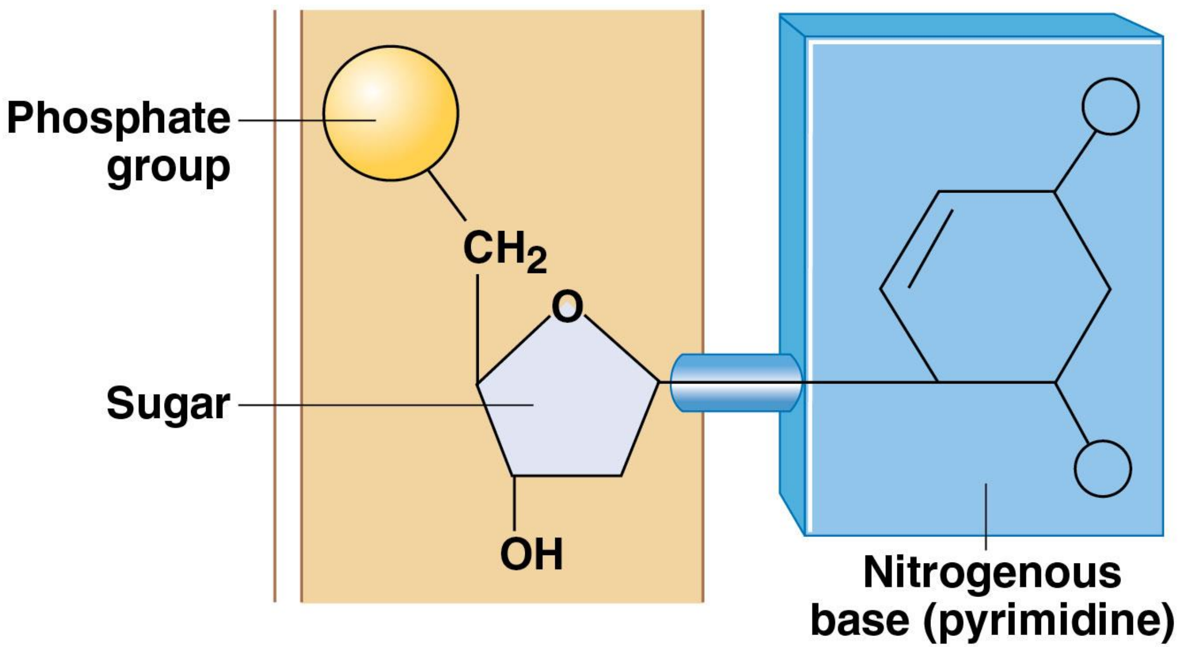
Nucleic acids

- Large organic molecules
- Composed of carbon, hydrogen, oxygen, nitrogen, and phosphorus
- Two classes
  1. **Deoxyribonucleic acid** (**DNA**)
  2. **Ribonucleic acid** (**RNA**)
- Primary function is storage and transfer of information
  - Particularly information for synthesis of proteins
- Consist of one or two long chains formed from dehydration synthesis of subunits (**nucleotides**)

Module 2.20: DNA and RNA

Nucleotide components

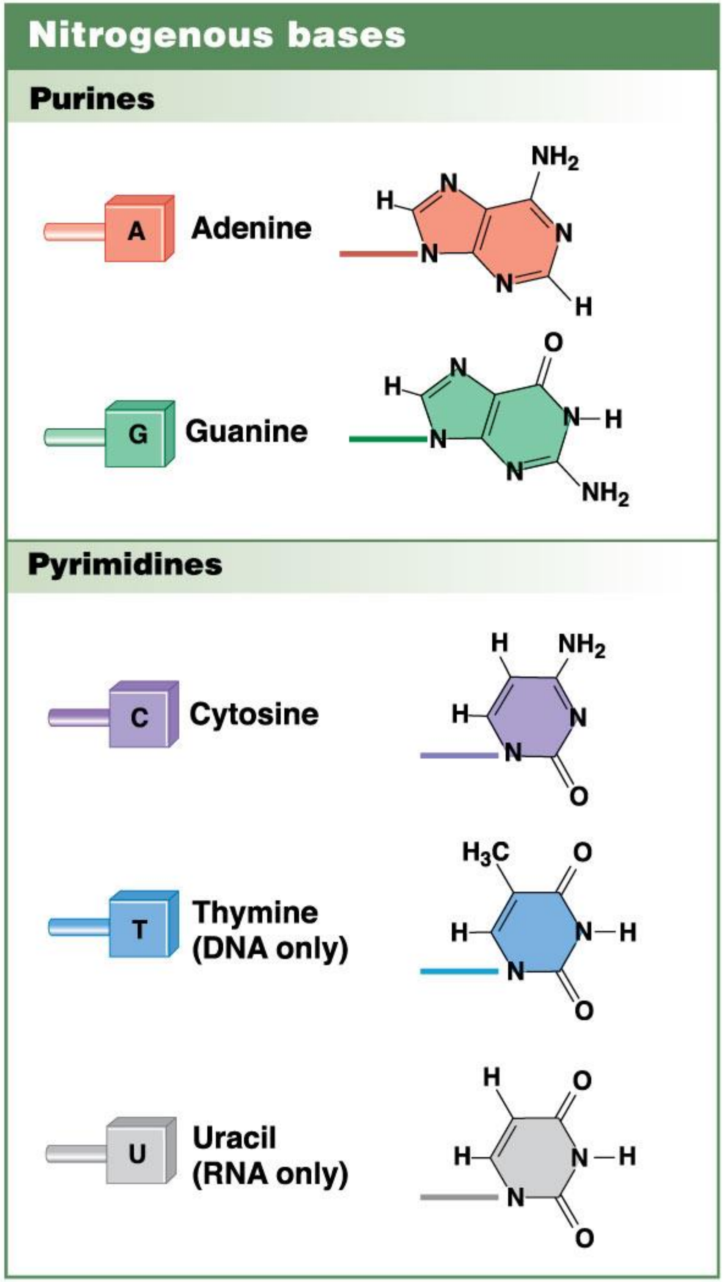
1. Phosphate group
2. Pentose (five-carbon) sugar
   - Either deoxyribose or ribose
3. **Nitrogenous base**



Module 2.20: DNA and RNA

Nucleotide components (continued)

1. **Nitrogenous base**
   a. **Purines**
      – **Adenine**
      – **Guanine**
   b. **Pyrimidines**
      – **Cytosine**
      – **Thymine** (only in DNA)
      – **Uracil** (only in RNA)

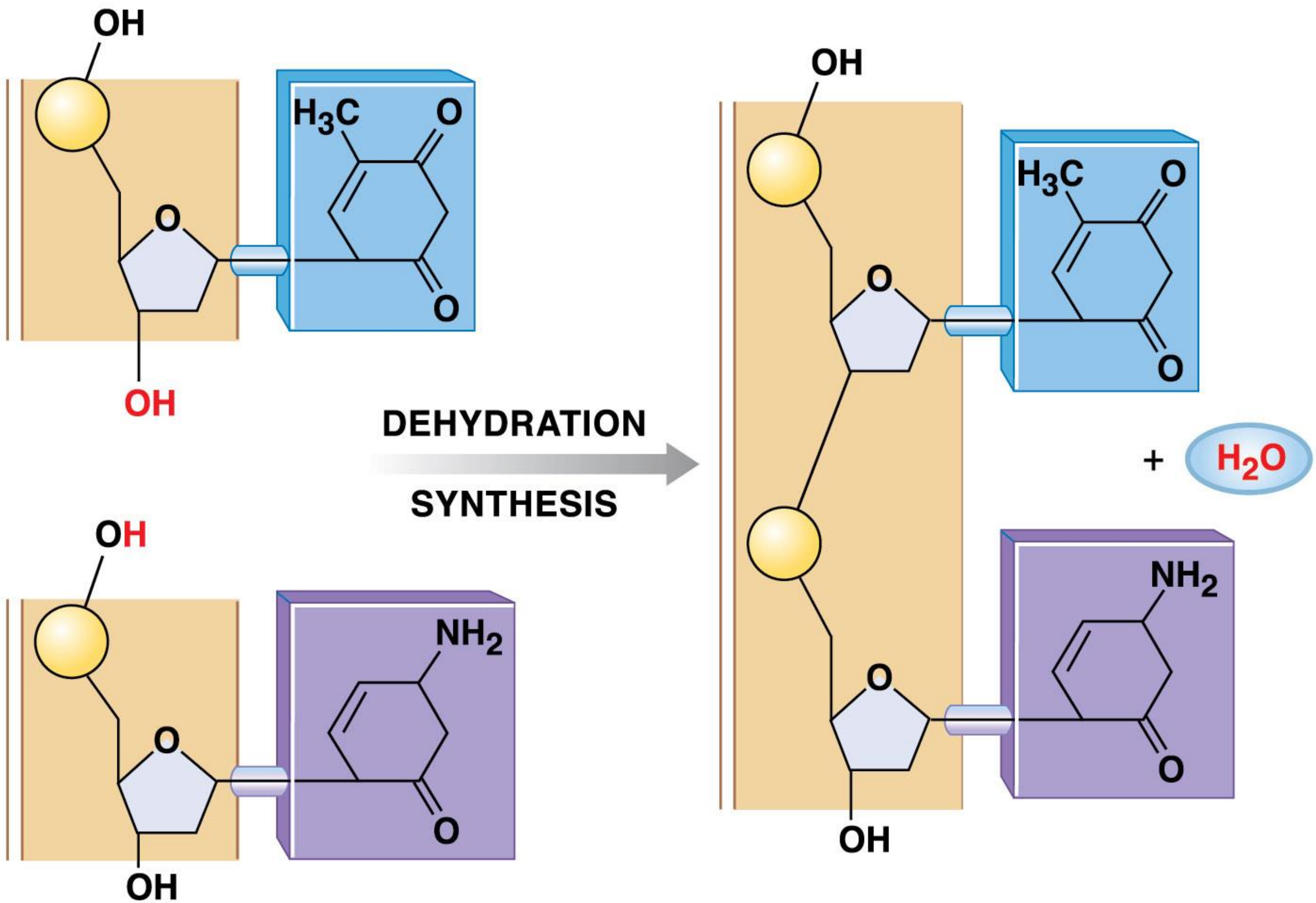


Module 2.20: DNA and RNA

Nucleic acid structure

- Phosphate and sugar of adjacent nucleotides bound together by dehydration synthesis
  - Produces a chain (“backbone”) of sugar-phosphate-sugar sequences with nitrogenous bases projecting to one side
  - Sequence of nitrogenous bases carries the information for protein synthesis

Nucleic acid structure

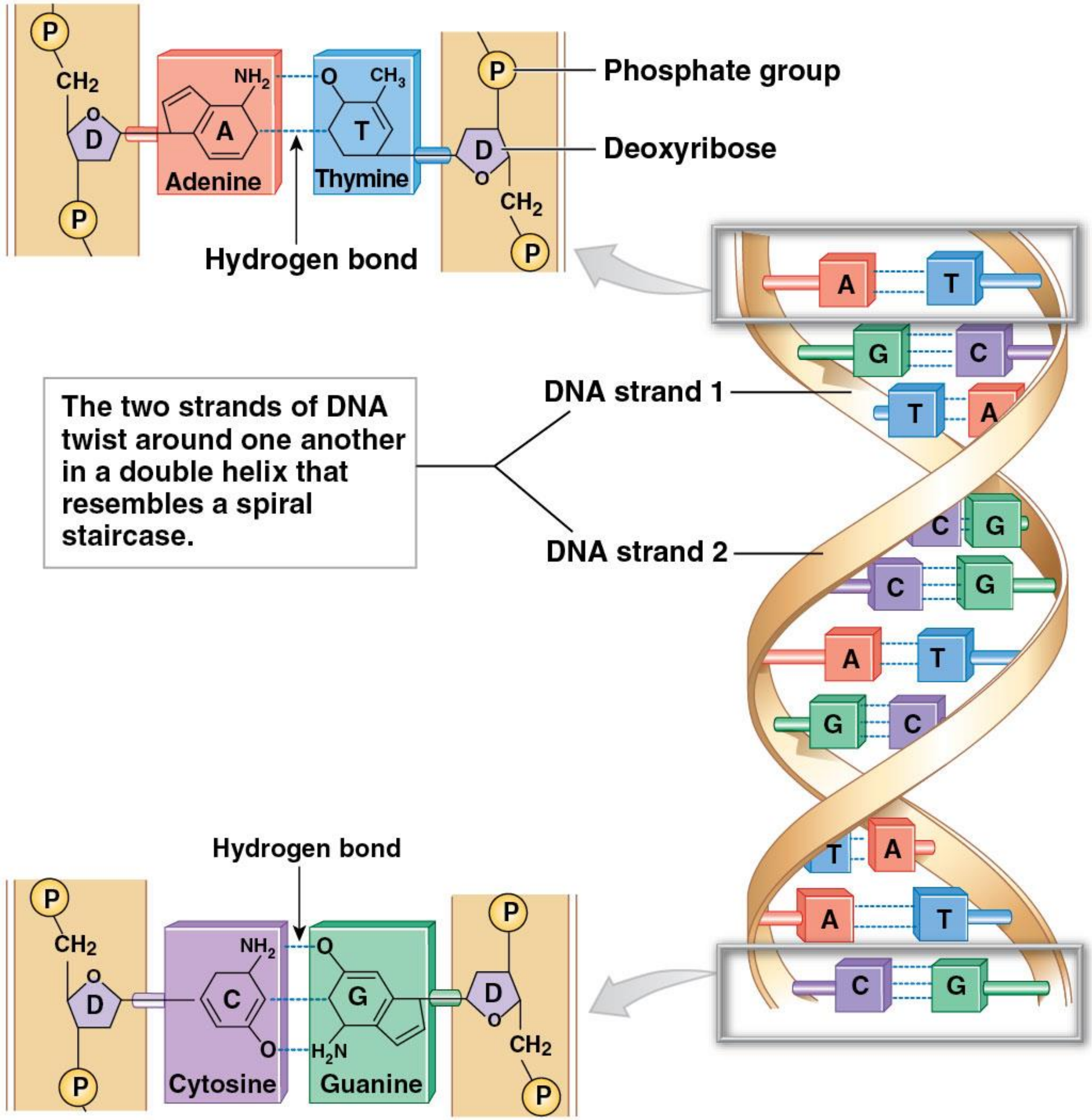


Module 2.20: DNA and RNA

DNA molecule

- Consists of pair of nucleotide chains
  - Pair called **complementary strands**
  - Strands twist around each other to form a double helix (like a spiral staircase)
- Hydrogen bonds between opposing nitrogenous bases hold two strands together
  - Have **complementary base pairs** due to the shapes of the bases
    - Adenine–Thymine (A–T)
    - Cytosine–Guanine (C–G)

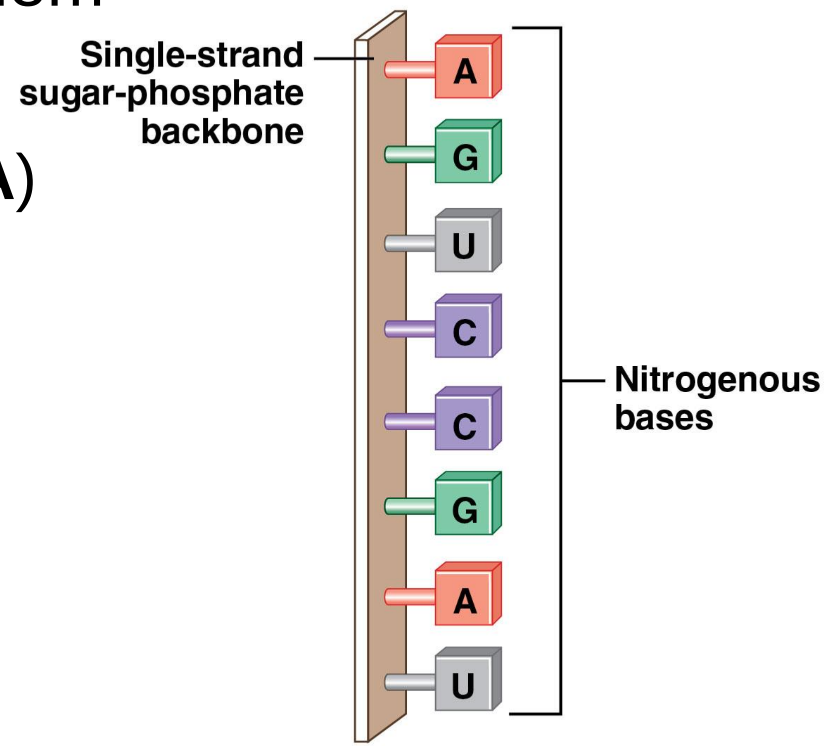
DNA molecule



Module 2.20: DNA and RNA

RNA molecule

- Single chain of nucleotides
- Shape and function depend on order of nucleotides and interactions between them
- Three types
  1. **Messenger RNA (mRNA)**
  2. **Transfer RNA (tRNA)**
  3. **Ribosomal RNA (rRNA)**



A Comparison of DNA with RNA

Characteristic	DNA	RNA
Sugar	Deoxyribose	Ribose
Nitrogenous bases	Adenine (A), guanine (G), cytosine (C), thymine (T)	Adenine, guanine, cytosine, uracil (U)
Number of nucleotides in typical molecule	Always more than 45 million	Varies from fewer than 100 to about 50,000
Molecular shape	Paired strands coiled in a double helix	Varies with hydrogen bonding along the length of the strand of each of the three main types (mRNA, tRNA, rRNA)
Function	Stores genetic information that controls protein synthesis	Performs protein synthesis as directed by DNA

Module 2.20: Review

A. Describe and identify the two classes of nucleic acids.
B. Explain how the complementary strands of DNA are held together.
C. Compare and contrast the nucleotides of DNA and RNA.

Learning Outcome: Compare and contrast the structures and functions of DNA and RNA.