HOUSTON HIGH SCHOOL

2026-2027 Pre-Term Work

Course Name	Honors Anatomy & Physiology
Teacher Name and Contact Email	Miriah Smith miriah.smith@gmsdk12.org
Pre-Term Work Assignment Description	Honors Anatomy & Physiology Recommended Summer Work Students should be familiar with all concepts covered in the "study guide" attached in the folder.
Purpose of Pre-Term Assignment	Knowledge of pre-requisite material required for Honors Anatomy & Physiology
Assignment Due Date	N/A
How will this assignment be submitted to the teacher?	It is not required to complete or turn in answers to any of these questions, but the "study guide" covers pre-requisite material for the honors anatomy & physiology course.
How will this assignment work be assessed (include rubric, if applicable)?	Students will be expected to have an understanding of this material for application in other topics.
Additional Resources:	See folder for pdfs of presentations that can help you review and the study guide questions. Khan academy, Crash Course, and Professor Dave explains are also good resources for additional understanding.

Honors Anatomy & Physiology Recommended Pre-term Work

Note: It is not required to complete or turn in answers to any of these questions, but the below "study guide" is pre-requisite material for the dual enrollment anatomy & physiology course, and students will be expected to have an understanding of this material for application in other topics.

In this folder you will find pdfs covering most of these topics to aid in your study.

Chemistry principles (should have been covered in biology):

1. Describe the differences between electrons, protons, and neutrons (Location, charge, mass).
2. Differentiate between atomic number, atomic mass, isotopes, and radioactive isotopes.
3. Distinguish between a molecule and a compound.
4. What is an ion? Cation? Anion? (Understand valence shells and octet rule)
5. Differentiate between ionic, covalent, and hydrogen bonds. Also, what are polar molecules?
6. Describe the four basic types of reactions: Synthesis, Decomposition, Exchange, and Reversible
7. What does the pH scale measure? What are acids and what are bases?
8. Distinguish between the types of carbohydrates: monosaccharides, disaccharides, and polysaccharides (starch, glycogen, and cellulose). What are the monomers called?
9. Distinguish between the types of lipids: triglycerides (unsaturated fats and saturated fats), steroids, and phospholipids.
10. Differentiate between the major types of proteins: fibrous and globular. What are the monomers called?
11. Describe the four levels of organization of proteins with regard to structure and how those structures are formed (think about interactions/bonds, and what it looks like).
12. Differentiate between the types of nucleic acids (RNA & DNA). What are the monomers called?

Cells:

13. Name the three major parts/divisions of the cell and describe their functions.
14. Describe the chemical structure of a cell membrane.
15. Describe the relative sizes and functions of microfilaments, intermediate filaments, and microtubules.
16. What is the difference between passive and active transport? List the types of substances that will readily diffuse across a cell's membrane.
17. Explain the differences between diffusion, facilitated diffusion, osmosis, and filtration (Passive transport mechanisms).
18. Distinguish among isotonic, hypertonic, and hypotonic solutions.
19. Describe and distinguish among the active transport mechanisms: simple active transport, all three types of endocytosis, exocytosis, and transcystosis.
20. Describe the stages of the cell cycle and then list and describe the stages of mitosis in the order of which they occur.

❖ You should also know functions of each cell organelle and nuclear component, as well as the differences between cilia, flagella, and microvilli. (There should be roughly 15 of these altogether including cilia, nuclear envelope, ribosomes, lysosomes, etc.)

Cellular Metabolism:

21. How does an enzyme control the rate of an reaction? What factors can alter an enzyme's ability?
22. Define cellular respiration and tell me the end (final) products.
23. What are aerobic and anaerobic reactions, and which one yields more energy?
24. What are the end results of glycolysis?
25. What is the role of oxygen in cellular respiration?
26. List the products of the citric acid cycle.
27. Explain the function of the electron transport chain.
28. List the steps of DNA replication.
29. List the steps of protein synthesis (transcription & translation).

Chapter 2 Chemical Basis of Life

HOLE'S ESSENTIALS OF HUMAN ANATOMY & PHYSIOLOGY

Charles J. Welsh

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



©Jman78/iStockphoto/GettyImages

© 2021 McGraw Hill. All rights reserved. Authorized only for instructor use in the classroom.
No reproduction or further distribution permitted without the prior written consent of McGraw Hill.

2.1: Introduction

Chemistry is the science that deals with the composition and characteristics of chemicals

A knowledge of chemistry is necessary for the understanding of physiology because of the importance of chemicals in body processes

Cells and their organelles are assemblies of molecules, which are composed of chemicals

© McGraw Hill

2.2: Fundamentals of Chemistry

Matter is anything that has weight (mass) and takes up space.

All matter is composed of elements

Elements are the smallest units of matter with specific chemical properties

Living organisms require about 20 elements, of which oxygen, carbon, hydrogen, and nitrogen are most abundant

Elements are composed of atoms; atoms of different elements vary in size, weight, and interaction with other atoms

Atoms are the smallest unit of an element

Attractions between two or more atoms are called **chemical bonds**

© McGraw Hill

Major Elements of the Body

TABLE 2.1 Elements in the Body

Major Elements	Symbol	Approximate Percentage of the Human Body (by weight)
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Chlorine	Cl	0.2
Sodium	Na	0.2
Magnesium	Mg	0.1
		Total 99.9%

© McGraw Hill

Trace Elements of the Body

TABLE 2.1 Elements in the Body

Trace Elements	
Chromium	Cr
Cobalt	Co
Copper	Cu
Fluorine	F
Iodine	I
Iron	Fe
Manganese	Mn
Zinc	Zn

Together less than 0.1%

© McGraw Hill

Atomic Structure

An atom consists of a central **nucleus** containing protons and neutrons, and electrons in orbit around the nucleus in shells

Protons have a positive charge, and are about equal in size to neutrons

Neutrons are uncharged

Electrons are much smaller than protons and neutrons, and have a negative charge

An electrically neutral atom has equal numbers of protons and electrons

Atoms that gain or lose one or more electrons become charged, and are called **ions**

© McGraw Hill

Atomic Number, Atomic Weight, and Isotopes

The number of protons in the atoms of an element is the **atomic number** of that element

The number of protons plus the number of neutrons approximates the **atomic weight**

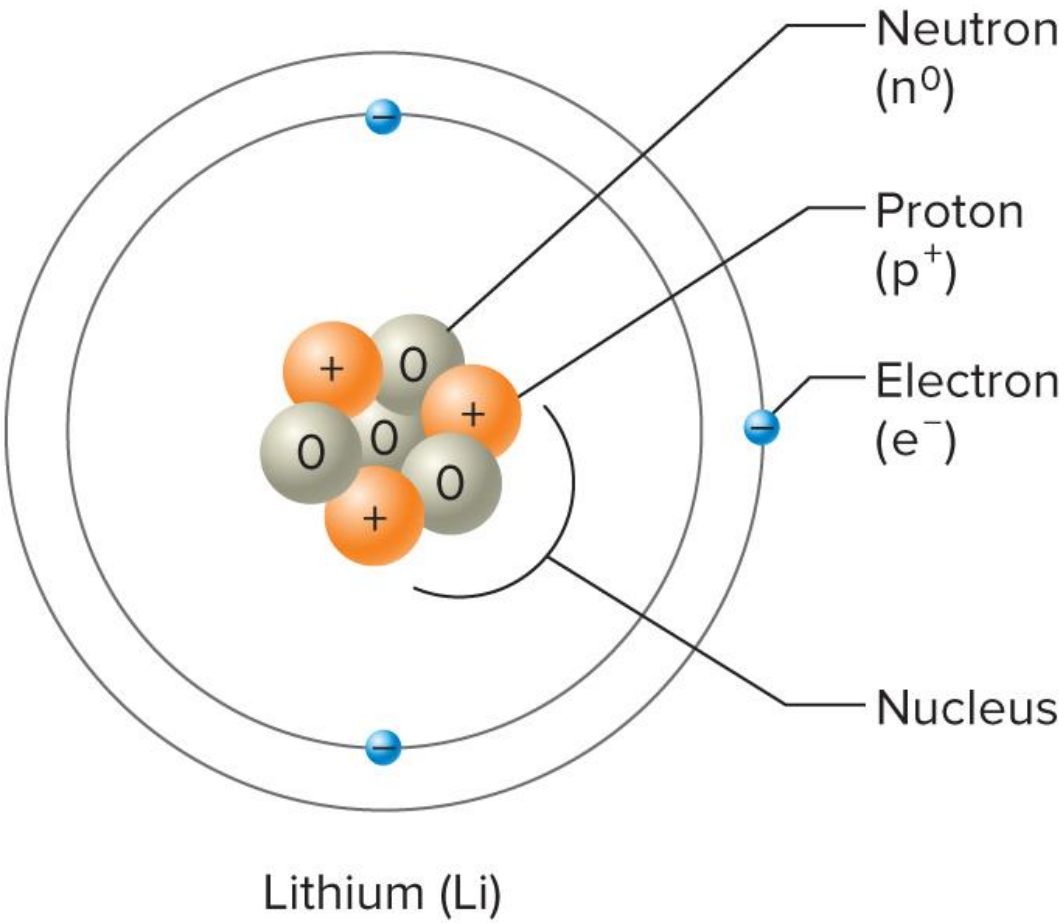
Atoms with the same atomic number, but different atomic weights are **isotopes** of that element:

- Example: All oxygen atoms have 8 protons, but may have 8, 9, or 10 neutrons. These atoms have atomic weights of 16, 17, or 18 respectively.
- Some isotopes are stable
- Unstable isotopes are radioactive, and give off radiation

© McGraw Hill

The Subatomic Particles of an Atom

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Bonding of Atoms

Atoms form **chemical bonds** by attaching to each other by gaining, losing, or sharing electrons

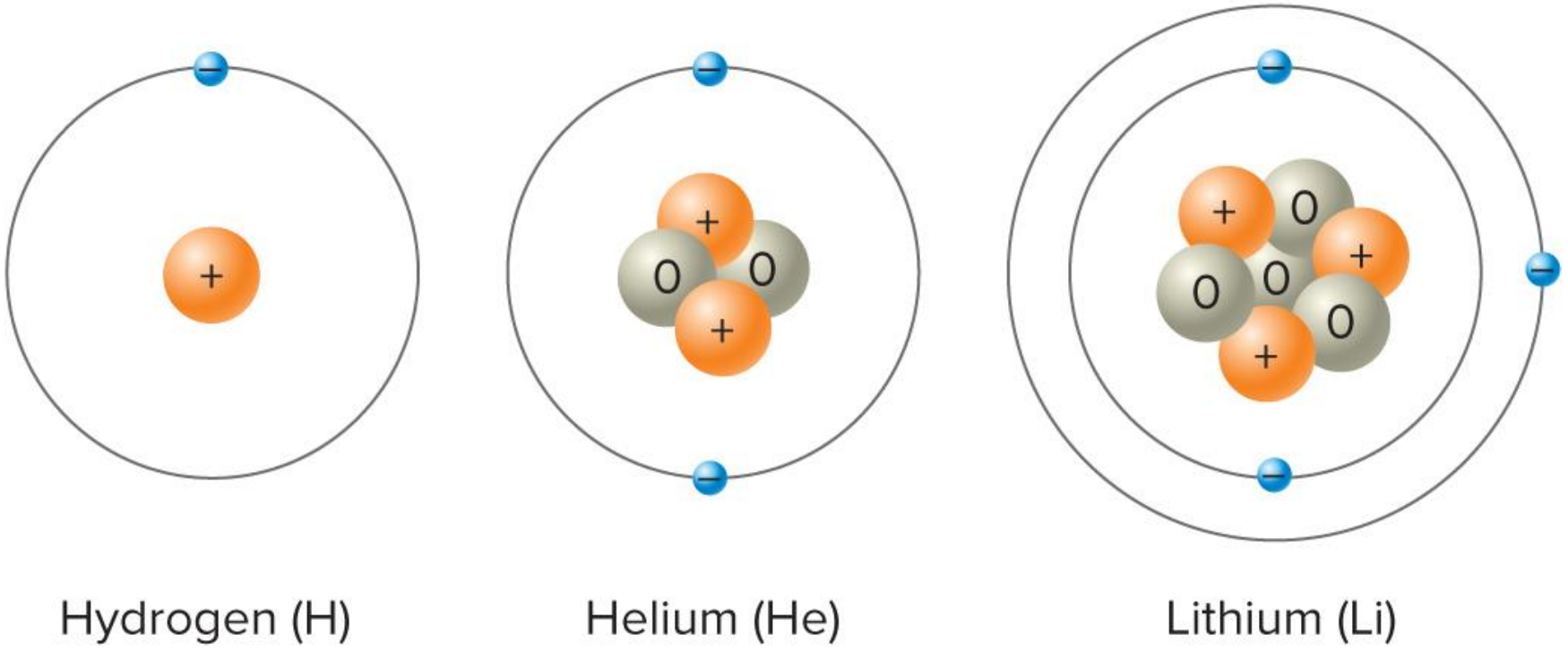
Electrons are found in **shells** (areas of space) around the nucleus

- The first shell, closest to the nucleus, holds a maximum of two electrons
- The second and third energy shells each hold a maximum of eight electrons
- Atoms of elements that have their outermost shells filled are **stable** and chemically **inert**

© McGraw Hill

Electron Orbits in the Shells of Atoms

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Ionic Bonding of Atoms

Atoms with incompletely filled outermost shells tend to be **reactive**, in order to form stable outer shells of 2 or 8 electrons

When atoms gain or lose electrons, they become **ions** with a charge. Whether they gain or lose electrons depends on how many electrons they have in their outermost shell

Oppositely-charged ions attract each other and form an **ionic bond**:

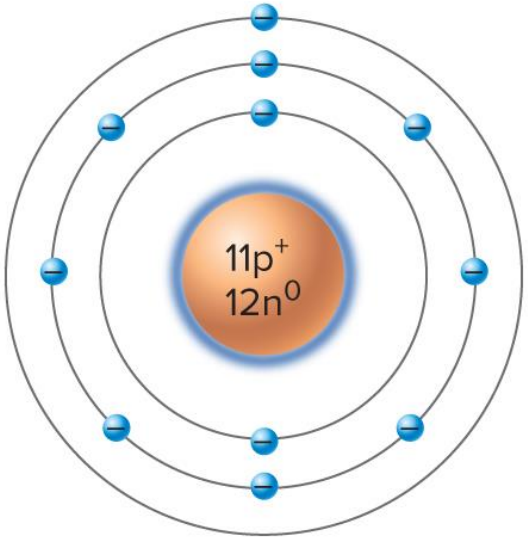
- Form crystal arrays, not molecules
- Formula gives the ratio of ions, not the actual numbers

Sodium atoms, for example, contain 1 electron in their outermost shells; they tend to lose 1 electron to form ionic bonds

© McGraw Hill

The Structure of a Sodium Atom

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



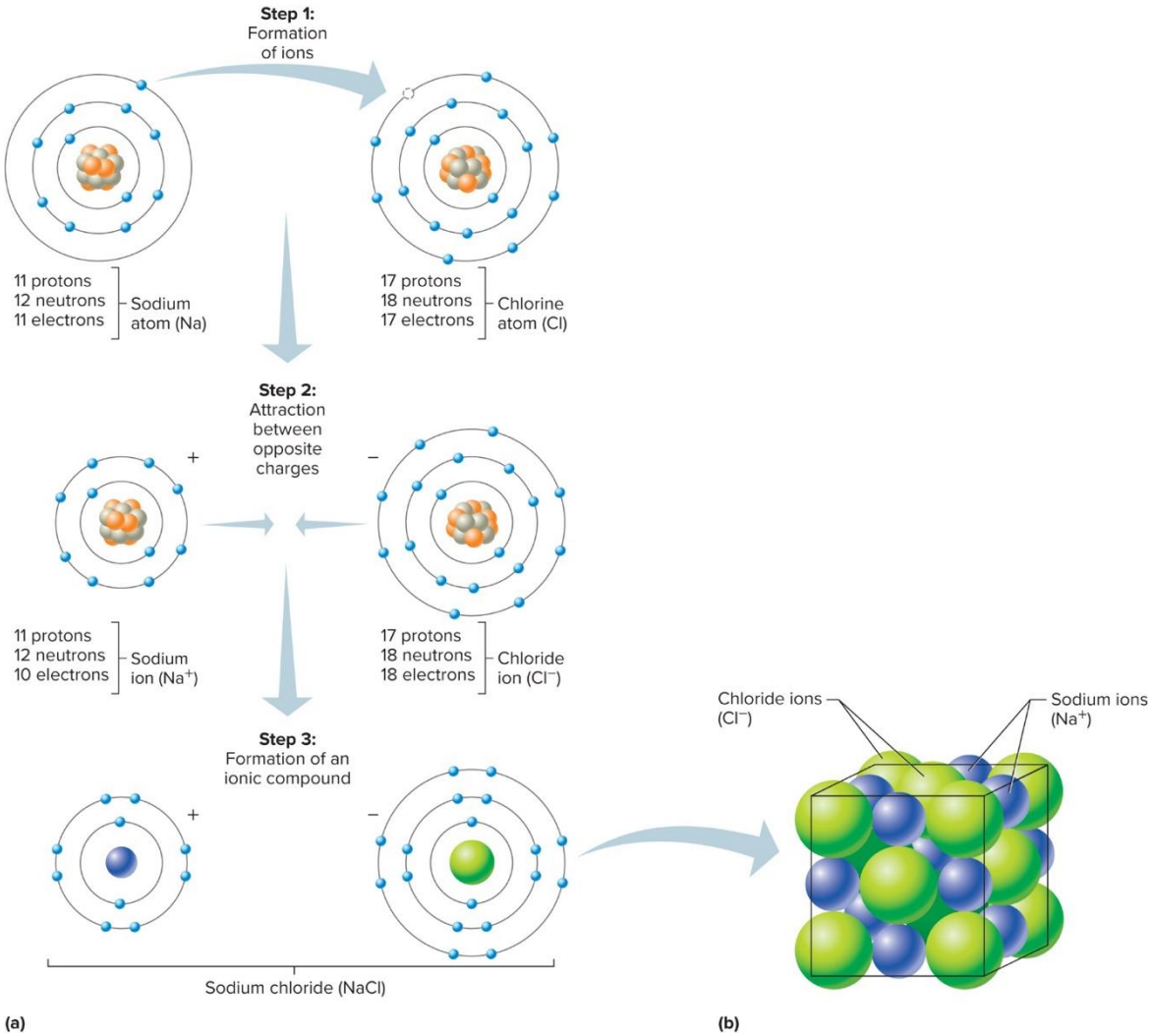
Sodium atom contains
11 electrons (e^-)
11 protons (p^+)
12 neutrons (n^0)

Atomic number = 11
Atomic weight = 23

Access the text alternative for slide images.

An Ionic Bond Between Sodium and Chlorine Atoms

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Covalent Bonding

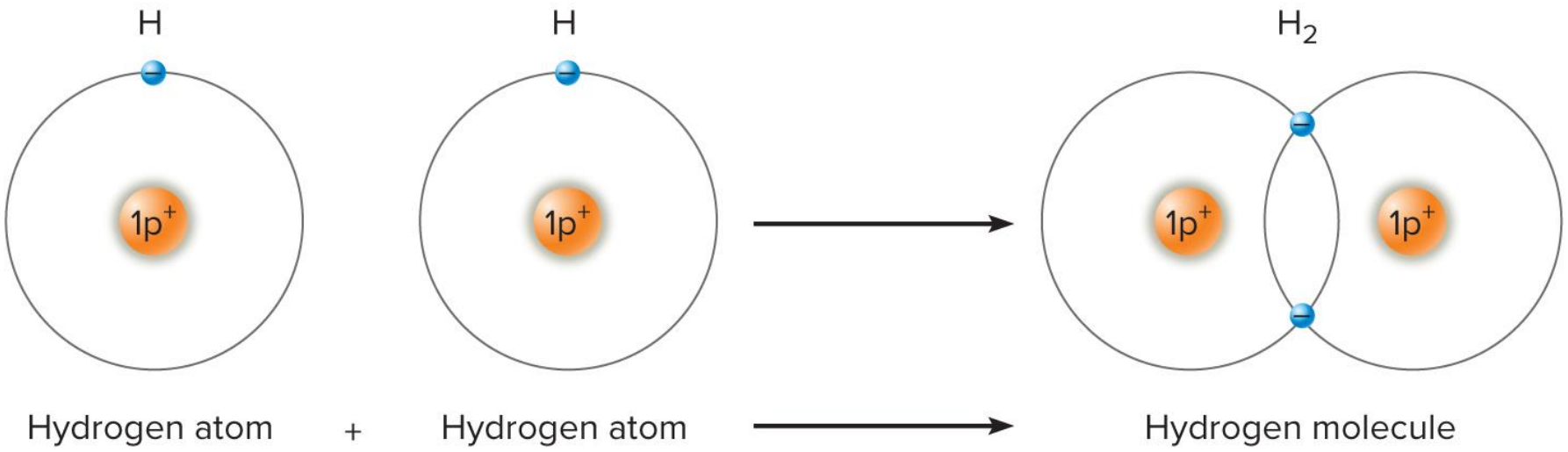
Covalent bonds are formed when atoms share electrons, in order to fill their outermost shells and become stable:

- One pair of electrons shared between two atoms forms a **single covalent bond**
  - Example: A hydrogen molecule is formed when 2 hydrogen atoms form a covalent bond by sharing a pair of electrons
- Two pairs of electrons shared between atoms form a **double covalent bond**
- Three pairs of electrons shared between atoms forms a **triple covalent bond**

© McGraw Hill

Covalent Bonding of 2 Hydrogen Atoms

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Polar Covalent and Hydrogen Bonds

Carbon and hydrogen atoms form **covalent bonds,** in which the electrons are shared equally

Some molecules contain a **polar covalent bond,** in which the electrons are not shared equally, but reside closer to one of the atoms in the bond

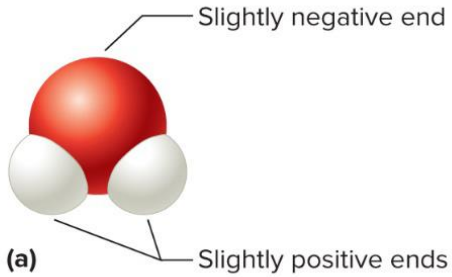
These molecules with unequal charge distribution are called **polar molecules**

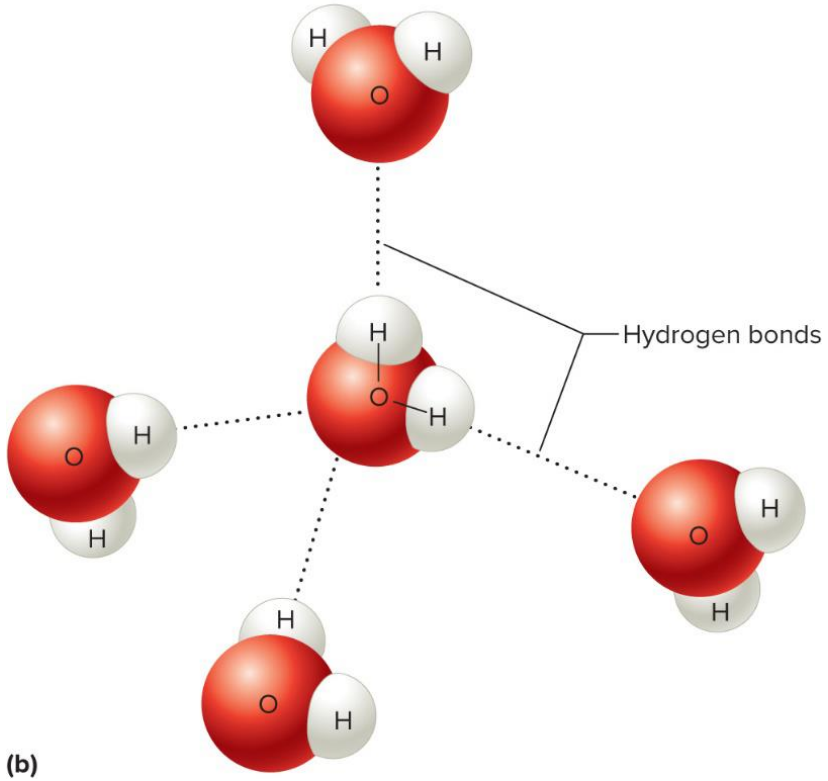
A **hydrogen bond** forms from the relatively weak attraction between the slightly positive H end of a polar molecule and the slightly negative N or O end of a nearby polar molecule

© McGraw Hill

Hydrogen Bonds between Water Molecules

Copyright © McGraw-Hill Education. Permission required for reproduction or display.





Access the text alternative for slide images.

Molecules and Compounds 1

A **molecule** is formed when two or more atoms form a chemical bond

If atoms of the same element bond, a molecule of that element is formed (O_2 is an oxygen molecule)

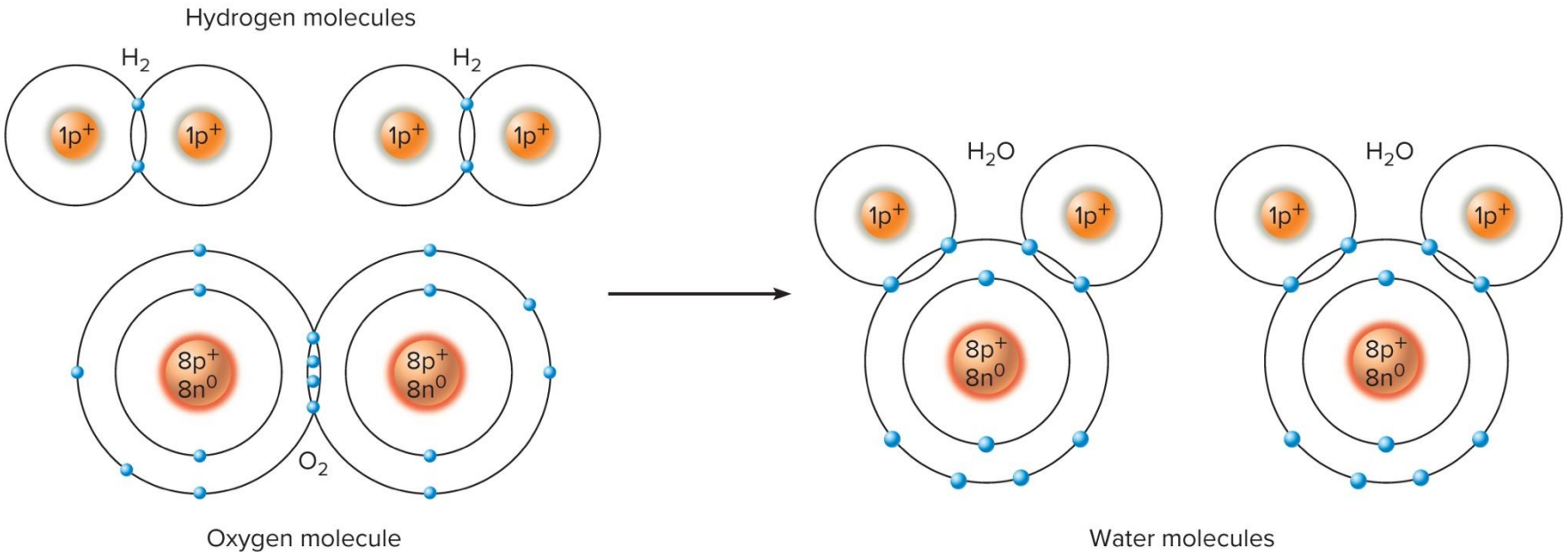
If atoms of different elements combine, the molecule is called a **compound**

- Compounds always have definite types and numbers of atoms
- For example, 2 atoms of H and 1 atom of O can bind to form a molecule of water, H_2O; since it contains different types of atoms, it is classified as a compound

© McGraw Hill

Molecules and Compounds 2

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Formulas 1

A **molecular formula** represents the numbers and types of atoms in a molecule

- Ex: Glucose = $C_6H_{12}O_6$, water = H_2O
- Glucose contains 6 C atoms, 12 H atoms, and 6 O atoms
- Water contains 2 H atoms and 1 O atom

Various representations, called structural formulas, can be used to illustrate how atoms are joined and arranged in molecules

© McGraw Hill

Formulas 2

Each atom forms a specific number of covalent bonds, based on the number of electrons it contains in its outermost shell:

- H atoms form single bonds, since they have 1 electron to share
- O atoms form double bonds, since they can share the 2 electrons in their outermost shell

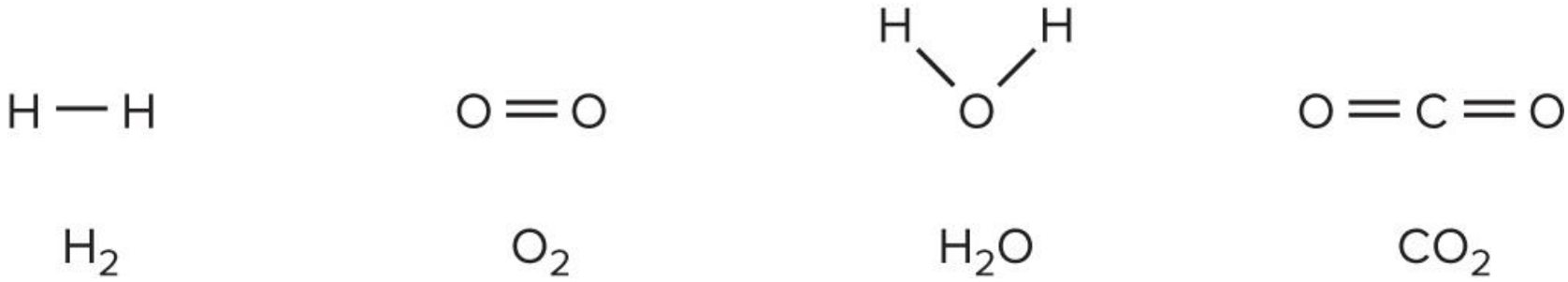
Structural formulas use single lines to illustrate single bonds, double lines represent double bonds, etc.

Three-dimensional molecular models show spatial relationships between atoms

© McGraw Hill

Structural and Molecular Formulas

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Three-dimensional Molecular Models

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a) A water molecule (H_2O), with the white parts depicting hydrogen atoms and the red part representing oxygen.



(b) A glucose molecule ($C_6H_{12}O_6$), in which the black parts represent carbon atoms.

Access the text alternative for slide images.

(a, b): Courtesy John W. Hole, Jr.

Chemical Reactions 1

A **chemical reaction** occurs as bonds are formed or broken between atoms, ions, or molecules

Substances that are changed by the reaction are called the **reactants**; those formed are the **products**

During **synthesis reactions,** two or more atoms or molecules bond together, forming a more complex product:

$$A + B \rightarrow AB$$

During **decomposition reactions,** larger molecules are broken into smaller ones, by breaking chemical bonds:

$$AB \rightarrow A + B$$

© McGraw Hill

Chemical Reactions 2

Exchange reactions occur as parts of molecules trade places, by breaking chemical bonds and forming new ones:

$$AB + CD \rightarrow AD + CB$$

Reversible reactions are ones in which the products can change back into the reactants; they are symbolized by using double arrows:

$$AB + CD \Leftrightarrow AD + CB$$

Catalysts influence the speed of chemical reactions without being used up in the process; catalysts in the body are called **enzymes**

© McGraw Hill

Acids and Bases

Substances that release ions in water are called **electrolytes;** these can carry electric charge in the body

When ionically bound substances are put into water, they **dissociate**, as the slightly positive ends of water molecules attract the negative ions, and the slightly negative ends of water molecules attract the positive ions; the ions then interact with the water molecules instead

Electrolytes that release hydrogen ions in water are called **acids**

Electrolytes that release ions that combine with hydrogen ions in water are called **bases**

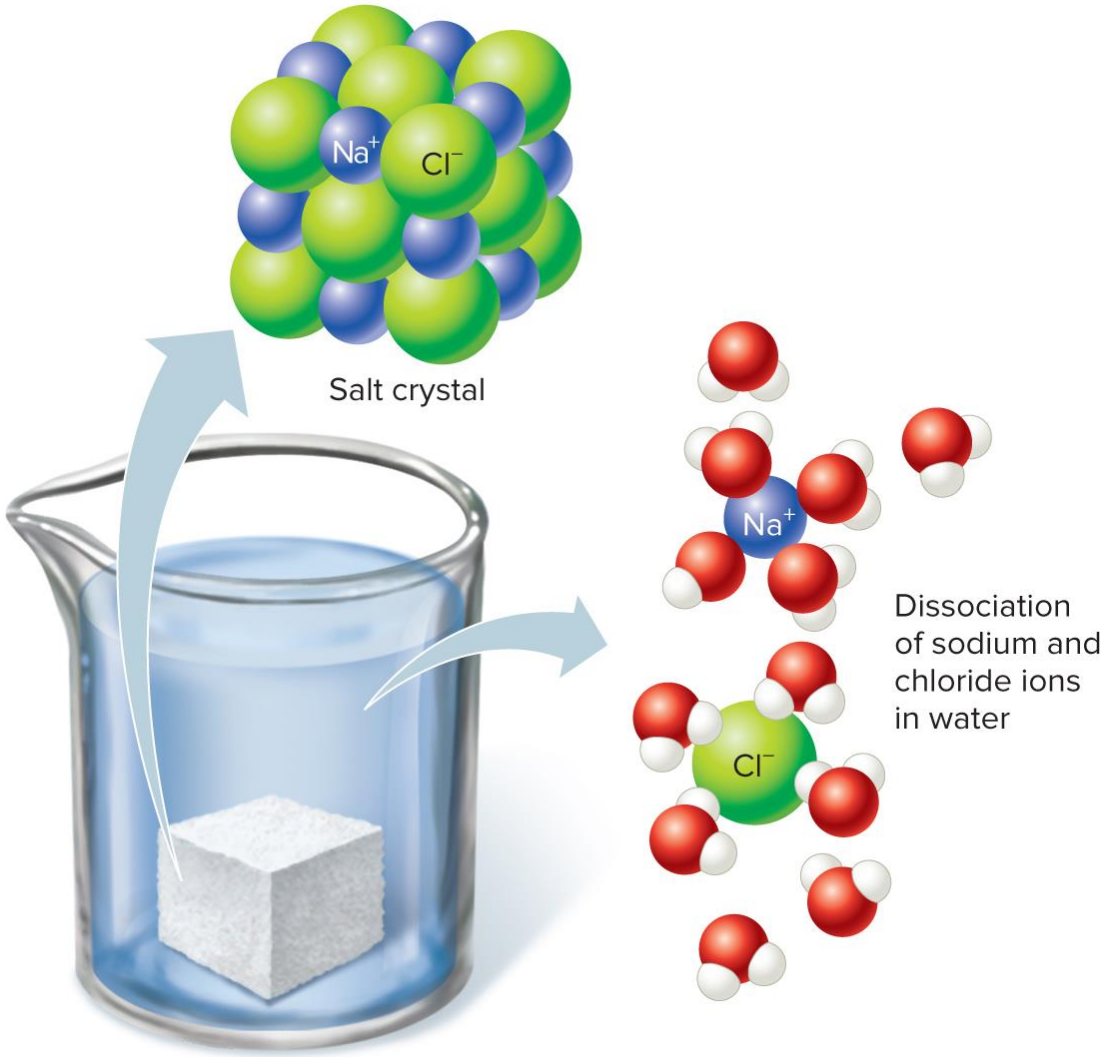
The concentrations of H^+ and OH^+ in the body are very important to physiology, since they affect chemical reactions that control many physiological functions

pH represents the concentration of hydrogen ions [H^+] in solution

© McGraw Hill

The Dissociation of NaCl in H_2O

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

The pH Scale [1]

The **pH scale** runs from 0 to 14, and measures H^+ ion concentration

A pH of 7 indicates a **neutral** solution with equal numbers of hydrogen ions and hydroxide (OH^-) ions.

A pH in the range of 0 to <7 indicates the presence of more hydrogen ions than hydroxide ions, and is considered **acidic**. The lower the pH, the more acidic the solution is.

A pH in the range of >7 to 14 indicates the presence of more hydroxide ions than hydrogen ions, and is considered **basic or alkaline**. The higher the pH, the more basic.

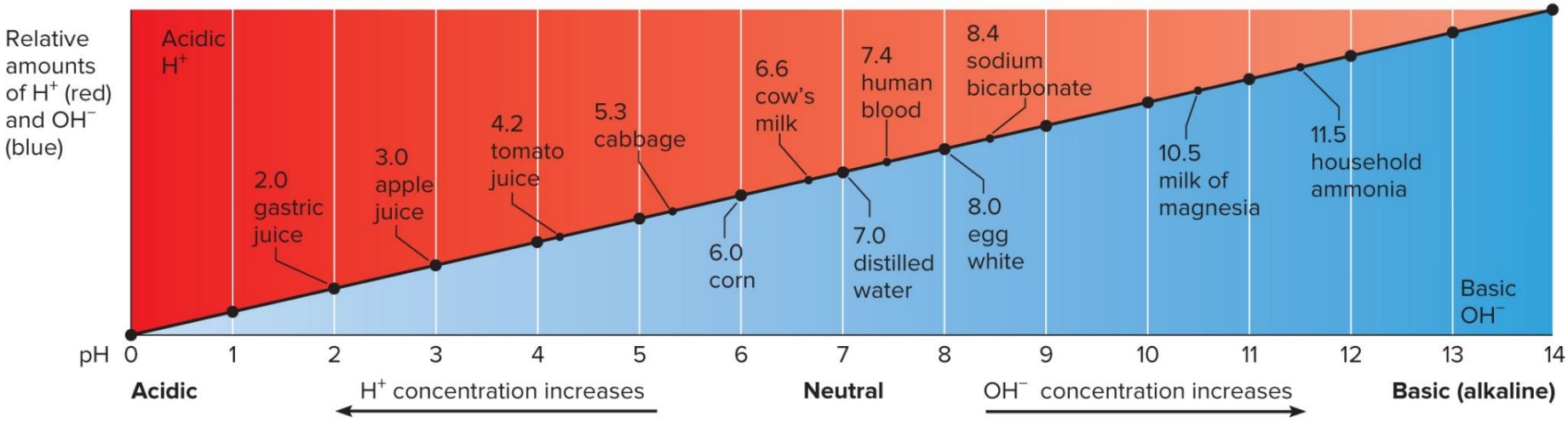
Between each whole number on the pH scale there is a tenfold difference in hydrogen ion concentration. A pH of 3 is ten times more acidic than a pH of 4.

Buffers are chemicals that combine with excess acids or bases to help minimize pH changes in body fluids.

© McGraw Hill

The pH Scale 2

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

2.3: Chemical Constituents of Cells

Chemicals in nature can be divided into 2 categories: organic and inorganic

Organic molecules or compounds contain both hydrogen and carbon; many dissolve in water, but do not release ions; these are called **nonelectrolytes**

All other compounds are considered **inorganic;** they usually dissolve in water and release ions, making them **electrolytes**

Examples of common inorganic substances are water, oxygen, carbon dioxide, and salts

© McGraw Hill

Inorganic Substances: Water

Water is the most abundant compound in living things, and makes up two-thirds of the weight of a human adult

Water is an important **solvent**, and most metabolic reactions occur in water; a solvent is a substance in which other substances dissolve

Water is important in transporting **solutes** (dissolved substances) in the body, since it is the major component of blood and other body fluids

Water absorbs and transports heat through the body

© McGraw Hill

Other Inorganic Compounds

Oxygen: needed to release energy from nutrients; this energy is used to drive the cell's metabolism

Carbon Dioxide: released as a waste product during energy-releasing metabolic reactions

Salts:

- Compounds consisting of oppositely charged ions
- Salts provide necessary ions including sodium, chloride, potassium, calcium, magnesium, phosphate, carbonate, bicarbonate, and sulfate
- These electrolytes play important roles in many of the body's metabolic processes, such as nerve impulse conduction, muscle contraction, and transport of substances across cell membranes

© McGraw Hill

Common Inorganic Substances 1

TABLE 2.2 Inorganic Substances Common in the Body

Substance	Symbol or Formula	Functions
I. Inorganic molecules		
Water	H_2O	Medium in which most biochemical reactions occur (section 1.5, Maintenance of Life); major component of body fluids (sections 2.3, Chemical Constituents of Cells); helps regulate body temperature (section 6.4, Skin Functions); transports chemical (sections 12.1, Introduction)
Oxygen	O_2	Used in energy release from glucose molecules (section 4.4, Energy for Metabolic Reactions)
Carbon dioxide	CO_2	Waste product that results from metabolism (section 4.4, Energy for Metabolic Reactions); reacts with water to form carbonic acid (section 16.6, Gas Transport)
II. Inorganic ions		
Bicarbonate ions	HCO_3^-	Helps maintain acid-base balance (section 18.5, Acid-Base Balance)
Calcium ions	Ca^{+2}	Necessary for bone tissue (section 7.2 Bone Structure), muscle contraction (section 8.3, Skeletal Muscle Contraction), and blood clotting (blood coagulation) (section 12.4, Hemostasis)
Carbonate ions	Ca_3^{-2}	Component of bone tissue (section 7.4, Bone Function)

© McGraw Hill

Common Inorganic Substances 2

TABLE 2.2 Inorganic Substances Common in the Body

Substance	Symbol or Formula	Functions
Chloride ions	Cl^-	Major extracellular negatively charged ion (section 18.2, Distribution of Body Fluids)
Hydrogen ions	H^+	pH of the internal environment (section 18.5, Acid-Base Balance)
Magnesium ions	Mg^{+2}	Component of bone tissue (section 7.4, Bone Function); required for certain metabolic processes (section 15.11, Nutrition and Nutrients)
Phosphate ions	PO_4^{-3}	Required for synthesis of ATP, nucleic acids, and other vital substances (section 4.4, Energy for Metabolic Reactions; section 4.5, DNA [Deoxyribonucleic Acid]; component of bone tissue (section 7.4, Bone Function); helps maintain polarization of cell membranes (section 9.6, Cell Membrane Potential)
Potassium ions	K^+	Required for polarization of cell membrances (section 9.6, Cell Membrane Potential)
Sodium ions	Na^+	Required for polarization of cell membrances (section 9.6, Cell Membrane Potential); helps maintain water balance (section 11.8, Adrenal Glands)
Sulfate ions	SO_4^{-2}	Helps maintain polarization of cell membrances (section 9.6, Cell Membrane Potential)

© McGraw Hill

Organic Substances: Carbohydrates

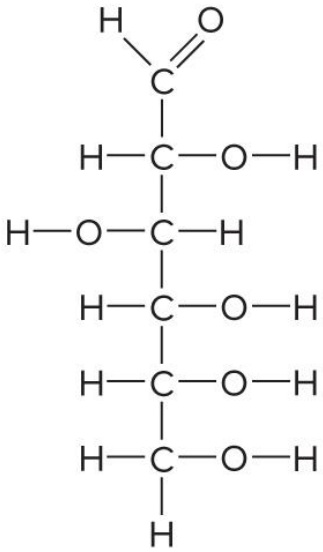
Carbohydrates:

- Provide energy for cellular activities and materials for synthesizing particular cell structures; are also stored as energy reserves
- Composed of carbon, hydrogen, and oxygen, typically with twice as many H atoms as O atoms
- **Monosaccharides (simple sugars):** the smallest carbohydrates; contain 5 to 6 C atoms; examples: glucose, fructose, galactose, ribose, deoxyribose
- **Disaccharides (double sugars):** consist of 2 simple sugars; examples: lactose, sucrose, maltose
- **Polysaccharides (many simple sugars):** consist of many glucose molecules joined together; examples: glycogen, starch

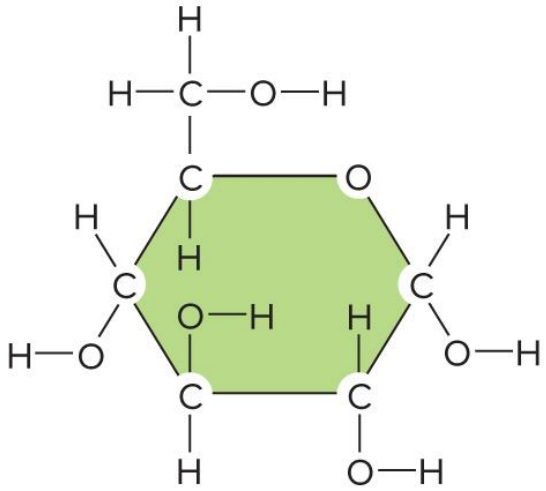
© McGraw Hill

Structural Formulas for Glucose

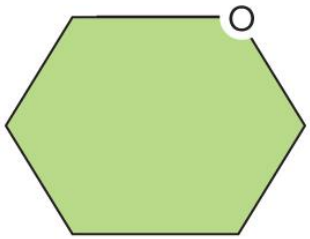
Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a) Some glucose molecules ($C_6H_{12}O_6$) have a straight chain of carbon atoms.



(b) More commonly, glucose molecules form a ring structure.

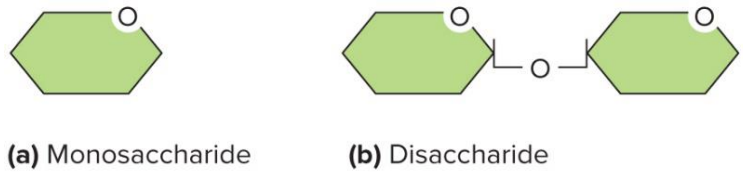


(c) This shape symbolizes the ring structure of a glucose molecule.

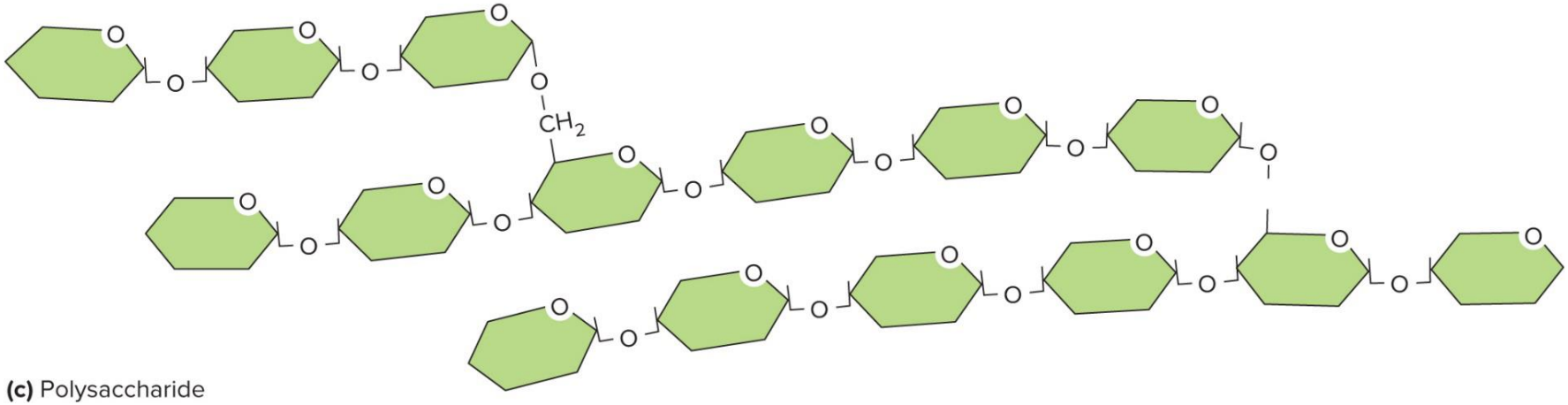
Access the text alternative for slide images.

Mono-, Di-, and Polysaccharides

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a) Monosaccharide (b) Disaccharide



(c) Polysaccharide

Access the text alternative for slide images.

Organic Substances: Lipids

Lipids are organic substances that are insoluble in water

Lipids include fats (triglycerides), phospholipids, and steroids

Triglycerides (fats) are the most abundant type of lipids

Triglycerides store and supply energy for cellular function

Triglycerides consist of glycerol and three fatty acids

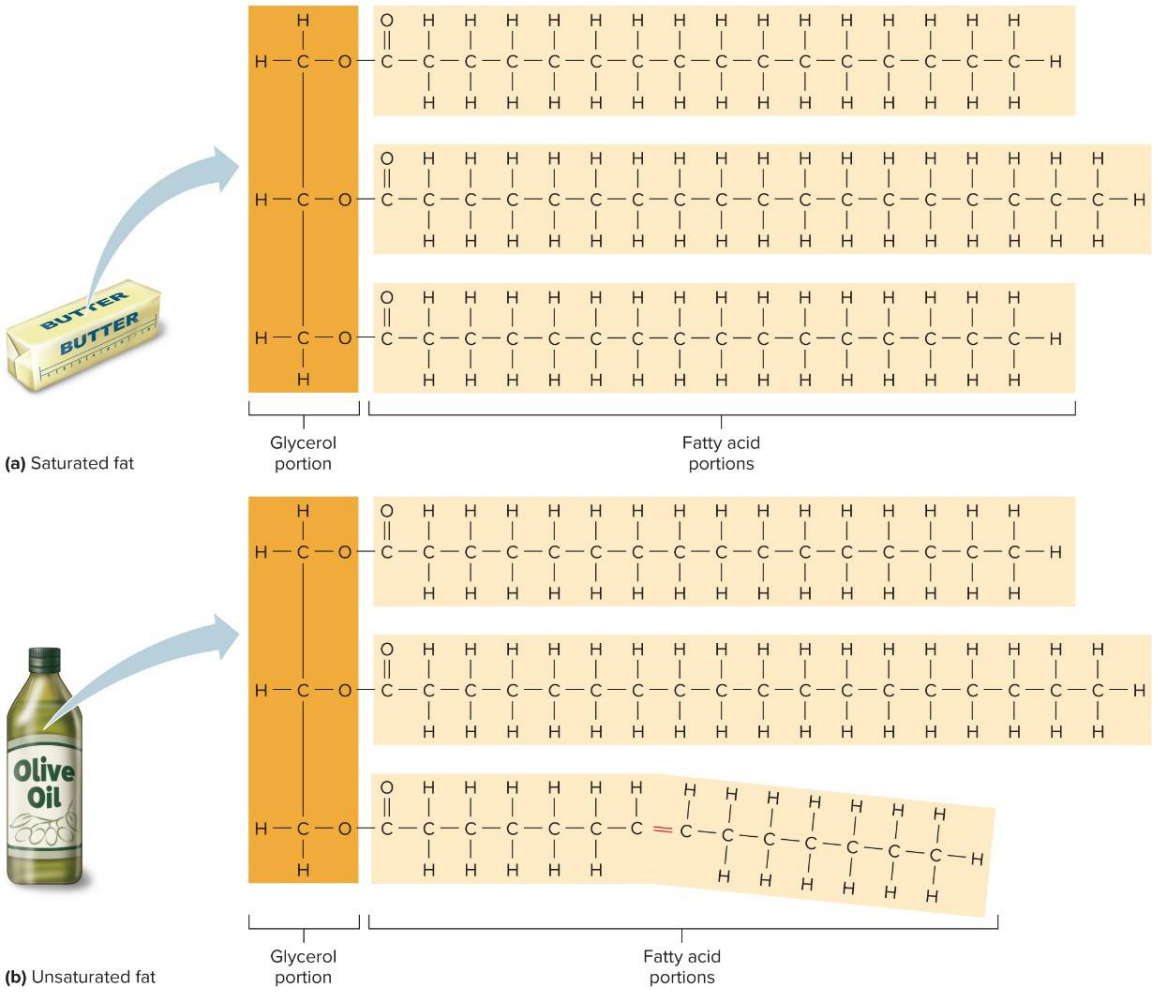
Triglycerides, like carbohydrates, consist of carbon, hydrogen, and oxygen, but have a smaller proportion of oxygen atoms than carbohydrates

- Fatty acids with all single carbon-carbon bonds are called **saturated fatty acids**
- Those with one or more double bonds between carbon atoms are called **unsaturated fatty acids**

© McGraw Hill

Structure of a Triglyceride

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Other Types of Lipids

Phospholipids:

- Consist of glycerol, two fatty acids, and a phosphate group
- Important in cell structures, such as plasma membranes

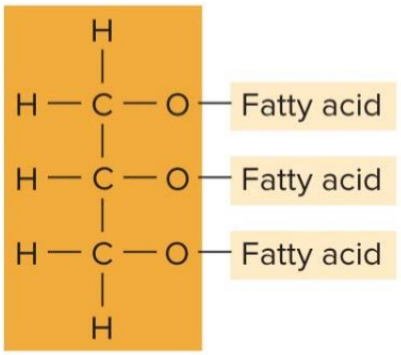
Steroids:

- Complex carbon ring structures
- A very important steroid is **cholesterol**, which is used to synthesize the sex hormones and several hormones from the adrenal glands

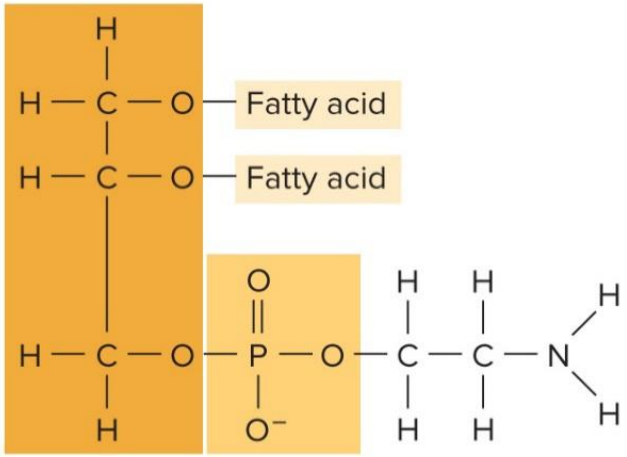
© McGraw Hill

Structure of Triglycerides and Phospholipids

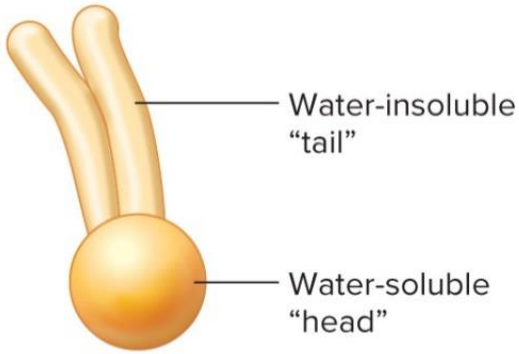
Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a) A triglyceride molecule



(b) A phospholipid molecule (the unshaded portion may vary)

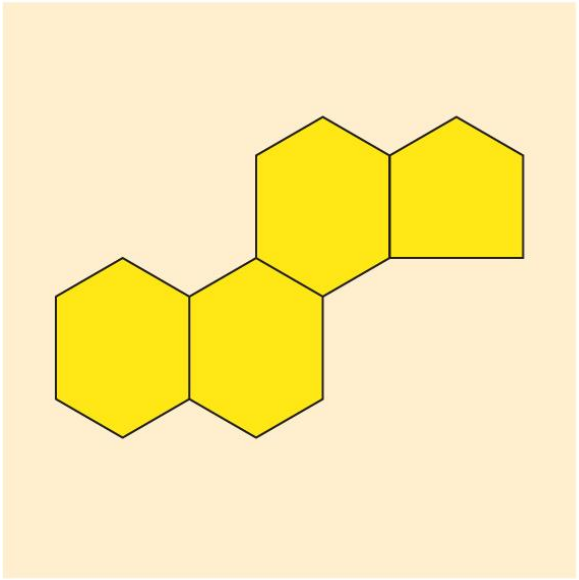


(c) Schematic representation of a phospholipid molecule

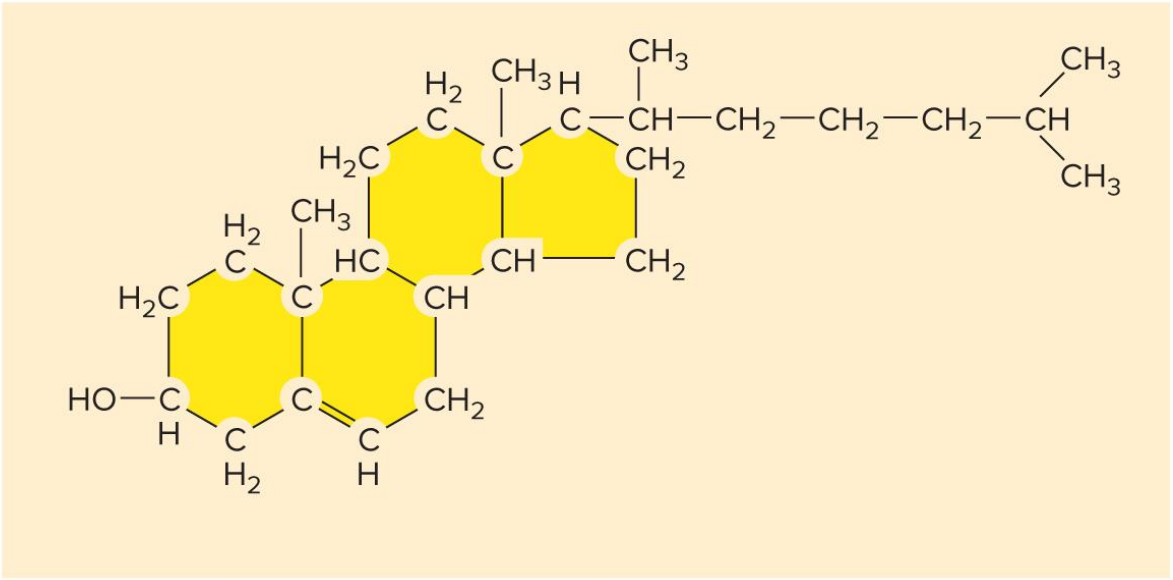
Access the text alternative for slide images.

Structure of Steroids

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a) General structure of a steroid



(b) Cholesterol

Access the text alternative for slide images.

Groups of Lipids

TABLE 2.3 Important Groups of Lipids

Group	Basic Molecular Structure	Characteristics
Triglycerides	Three fatty acid molecules bound to a glycerol molecule	The most common lipids in the body; stored in fat tissue as an energy supply; fat tissue also provides thermal insulation beneath the skin
Phospholipids	Two fatty acid molecules and a phosphate group bound to a glycerol molecule	Used as structural components in cell membranes; abundant in liver and parts of the nervous system
Steroids	Four connected rings of carbon atoms	Widely distributed in the body and have a variety of functions; include cholesterol, hormones of adrenal cortex and hormones from the ovaries and testes

© McGraw Hill

Organic Substances: Proteins

Proteins are organic compounds containing C, O, H, and N (nitrogen) atoms; some also contain S (sulfur)

Proteins have a great variety of functions in the body: as structural materials, energy sources, certain hormones, receptors on cell membranes, antibodies, and enzymes to catalyze metabolic reactions

Proteins consist of building blocks called **amino acids**, each of which contains a carboxyl group, an amino group and a side chain called the R group

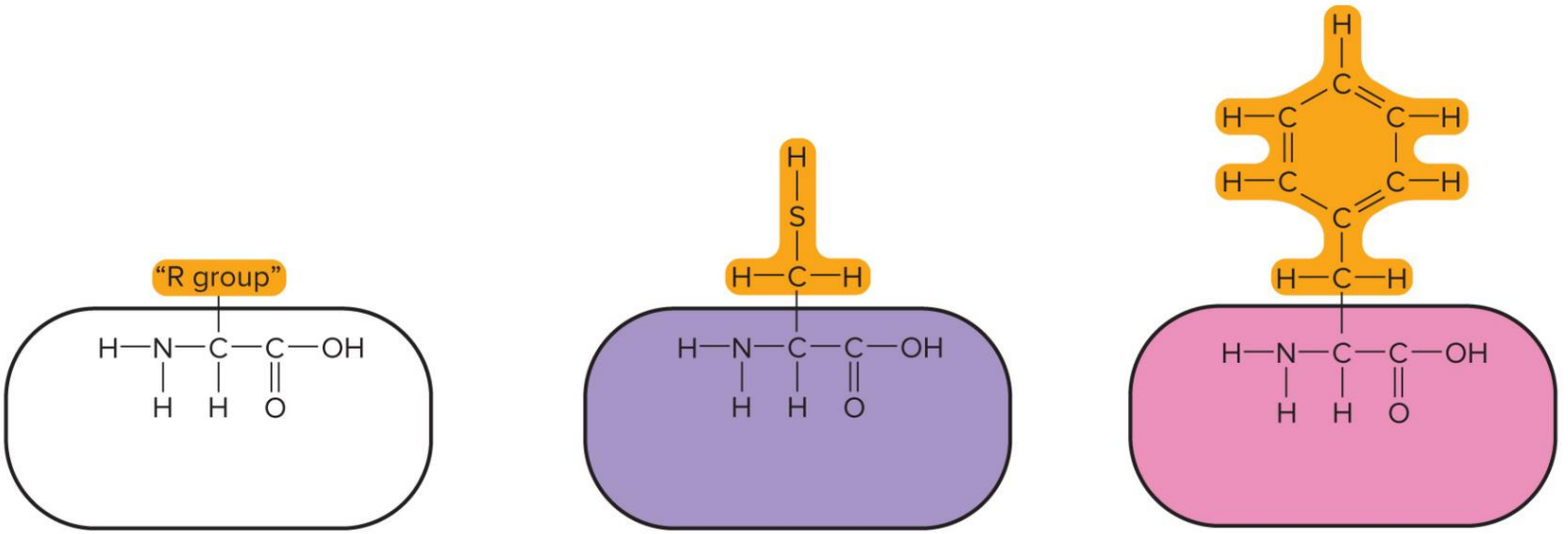
Most living organisms have 20 different amino acids making up their proteins

Amino acids bind together in **polypeptide chains** of <100 to >5000 amino acids

© McGraw Hill

Structure of Amino Acids

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a) General structure of an amino acid. The portion common to all amino acids is within the oval. It includes the amino group ($—NH_2$) and the carboxyl group (—COOH). The "R group," or the "rest of the molecule," varies and is what makes each type of amino acid unique.

(b) Cysteine. Cysteine has an R group that contains sulfur.

(c) Phenylalanine. Phenylalanine has a complex R group.

Access the text alternative for slide images.

Levels of Structure in Proteins 1

Proteins have complex shapes held together by various types of chemical bonds:

- **Primary structure:** the sequence of amino acids
- **Secondary structure:** pleated or twisted coil structure, resulting from hydrogen bonds between some of the amino acids
- **Tertiary structure:** unique folded structure of a protein, due to attractions between amino acids in different parts of the protein molecule
- **Quaternary structure:** Another level of structure, found only in proteins that consist of more than one polypeptide chain; example: Hemoglobin consists of 4 polypeptide chains

© McGraw Hill

Protein Conformation and Denaturation

Conformation:

- Unique 3-dimensional shape of a protein, due to hydrogen and covalent bonding in different parts of the polypeptide chain
- Determines the function of a protein
- Can be long and fibrous or globular
- A slight, reversible change in conformation can be part of a protein's normal functioning

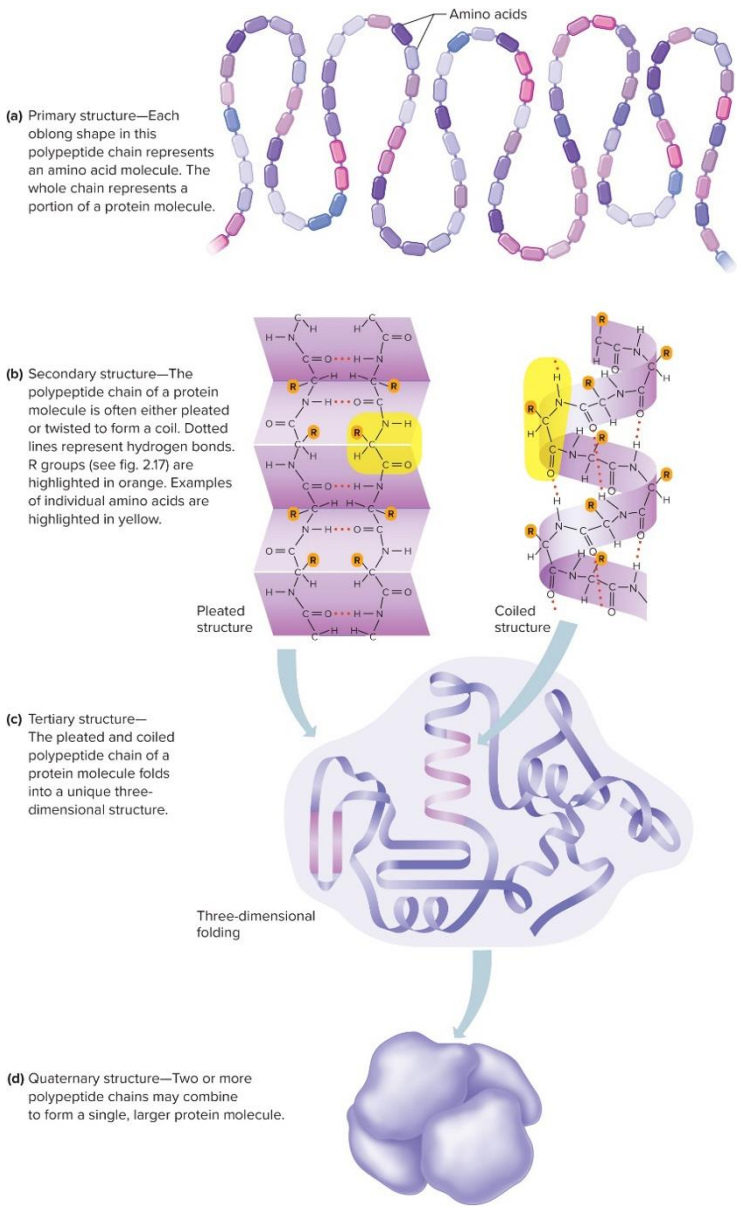
Denaturation:

- Irreversible disruption of a protein's shape, and loss of function, due to breaking of hydrogen bonds
- Caused by pH changes, excessive temperature changes, radiation, or chemicals
- Example: Hard-boiling of an egg denatures the albumin

© McGraw Hill

Copyright © McGraw-Hill Education. Permission required for reproduction or display.

Levels of Structure in Proteins 2



Access the text alternative for slide images.

Organic Substances: Nucleic Acids

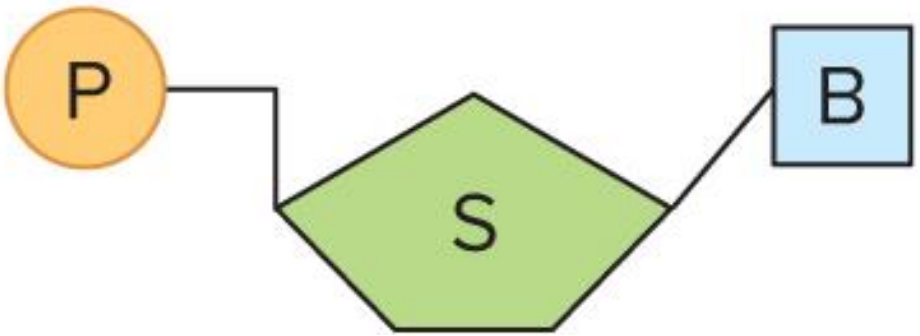
Nucleic acids:

- Form genes and participate in protein synthesis
- Large organic molecules
- Contain carbon, hydrogen, oxygen, nitrogen, and phosphorus, which form building blocks called **nucleotides**
- Each nucleotide consists of a 5-carbon sugar, a phosphate group, and one of five nitrogenous bases
- Nucleic acid molecules are chains of nucleotides

© McGraw Hill

Structure of a Nucleotide

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Types of Nucleic Acids 1

Nucleic acids are of two major types (RNA and DNA):

RNA (ribonucleic acid):

- Single-stranded
- Functions in protein synthesis
- Contains the sugar, ribose

© McGraw Hill

Types of Nucleic Acids 2

DNA (deoxyribonucleic acid):

- Double-stranded, twisted into a spiral, held together with hydrogen bonds
- Stores the molecular (genetic) code in genes, which is used by cells to synthesize proteins
- Contains the sugar, deoxyribose

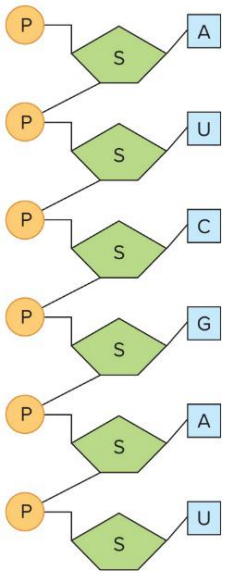
Adenosine triphosphate (ATP):

- A modification of RNA that contains three phosphate groups
- Stores and provides energy for chemical reactions in the body

© McGraw Hill

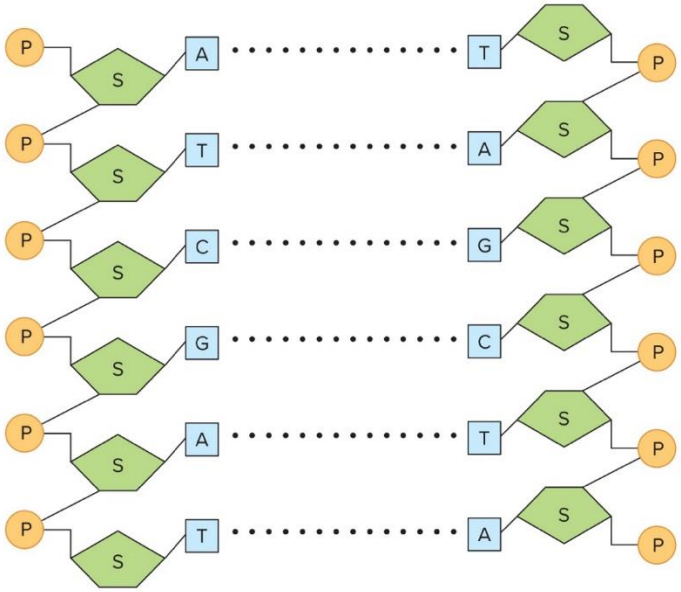
Nucleic Acid Structure: RNA and DNA

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a) RNA

Copyright © McGraw-Hill Education. Permission required for reproduction or display.

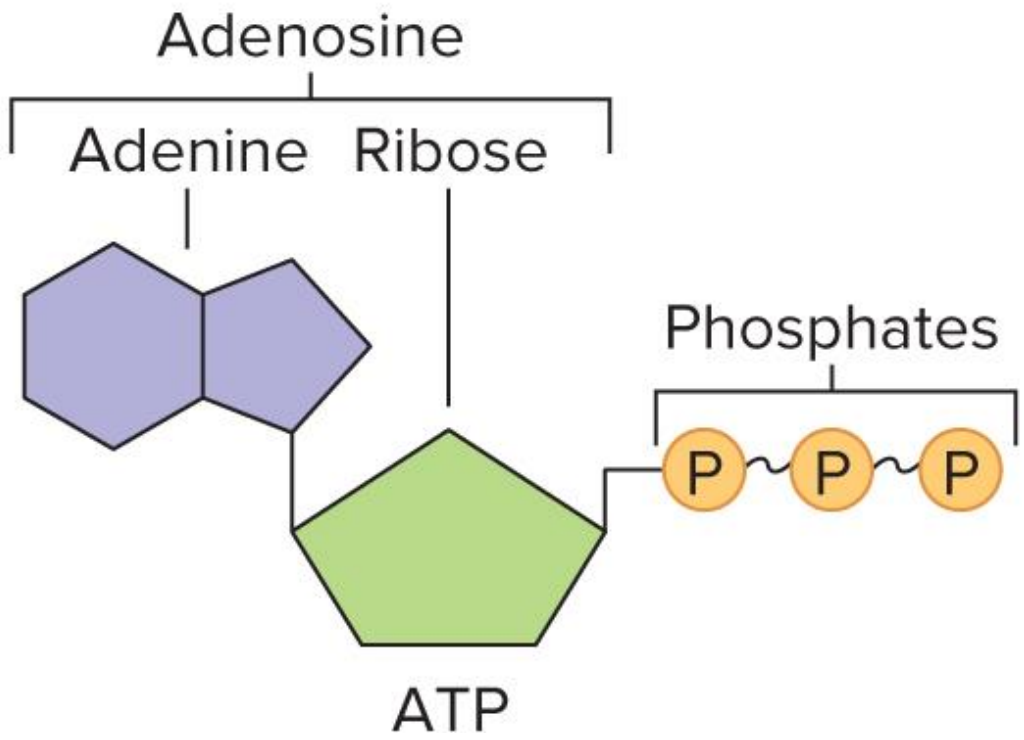


(b) DNA

Access the text alternative for slide images.

Structure of Adenosine Triphosphate (ATP)

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Organic Compounds in Cells

TABLE 2.4 Organic Compounds in Cells

Compound	Elements Present	General Form	Functions	Examples
Carbohydrates	C,H,O	Monosaccharide Disaccharide Polysaccharide	Provide energy, cell structure	Glucose Sucrose Glycogen
Lipids	C,H,O (often P)	Triglyceride Phospholipid Steroid	Provide energy, cell structure	Fats Cholesterol
Proteins	C,H,O,N (often S)	Polypeptide Chain	Provide cell structure, enzymes, energy	Albumins, hemoglobin
Nucleic acids	C,H,O,N,P	Polynucleotide chain	Store information for protein synthesis; control cell activities	RNA, DNA

© McGraw Hill



Because learning changes everything.®

www.mheducation.com

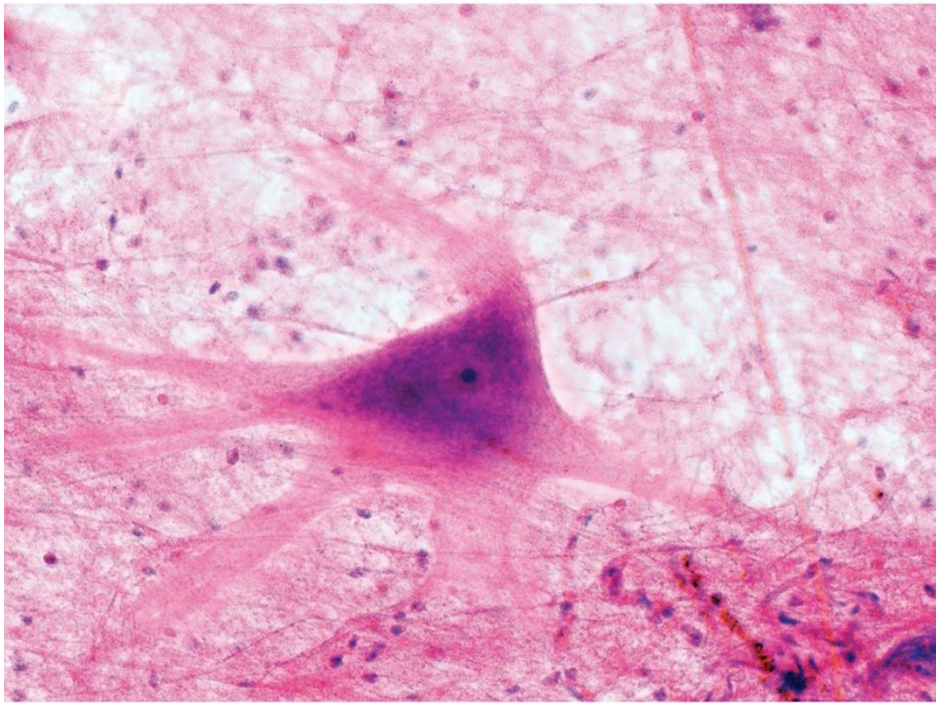
© 2021 McGraw Hill. All rights reserved. Authorized only for instructor use in the classroom.
No reproduction or further distribution permitted without the prior written consent of McGraw Hill.

Chapter 3
Cells

HOLE'S ESSENTIALS OF HUMAN ANATOMY & PHYSIOLOGY

Charles J. Welsh

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



© 2021 McGraw Hill. All rights reserved. Authorized only for instructor use in the classroom.
No reproduction or further distribution permitted without the prior written consent of McGraw Hill.

3.1: Introduction

A **cell** is the smallest unit of life

A cell continually carries out metabolic activities essential for life, as well as specialized functions, and adapts to changing conditions

Cells interact to form tissues, organs, and organ systems

The human body consists of 30 trillion cells that vary considerably in shape and size, yet have much in common

Differences in cell shape make different functions possible

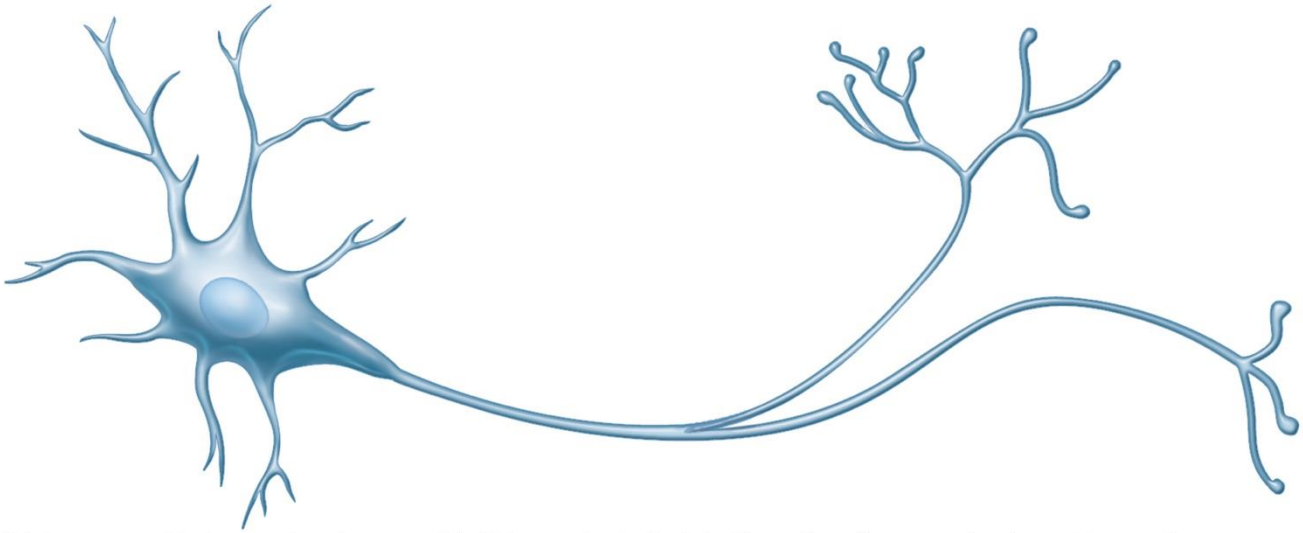
- Examples: Nerve cells have long extensions that conduct electrical impulses, while epithelial cells in the mouth are flat, thin, and densely packed, to provide a protective barrier

Genes control a cell's actions and responses

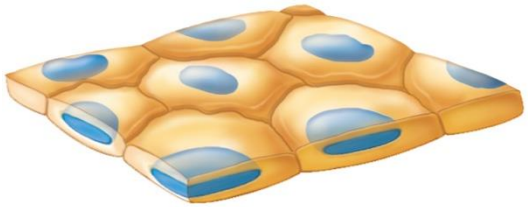
© McGraw Hill

Cells Vary in Shape and Function

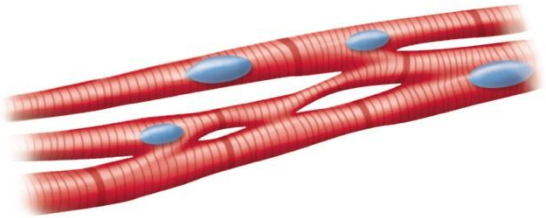
Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a) A nerve cell's long extensions enable it to conduct electrical impulses from one body part to another.



(b) The sheetlike organization of epithelial cells enables them to protect underlying cells.



(c) The alignment of contractile proteins within muscle cells enables them to generate forces, pulling closer together the structures to which they attach.

Access the text alternative for slide images.

3.2: Composite Cell

A **composite cell** includes many different cell structures; most cells contain most of these structures, but no cell contains all of them.

A cell consists of three main parts:

- **Nucleus**: Contains DNA (genetic material) and directs cell's activities
- **Cytoplasm:** Organelles and fluids that make up the majority of the cell; between nucleus and cell membrane
- **Cell membrane:** Boundary that encloses the cell

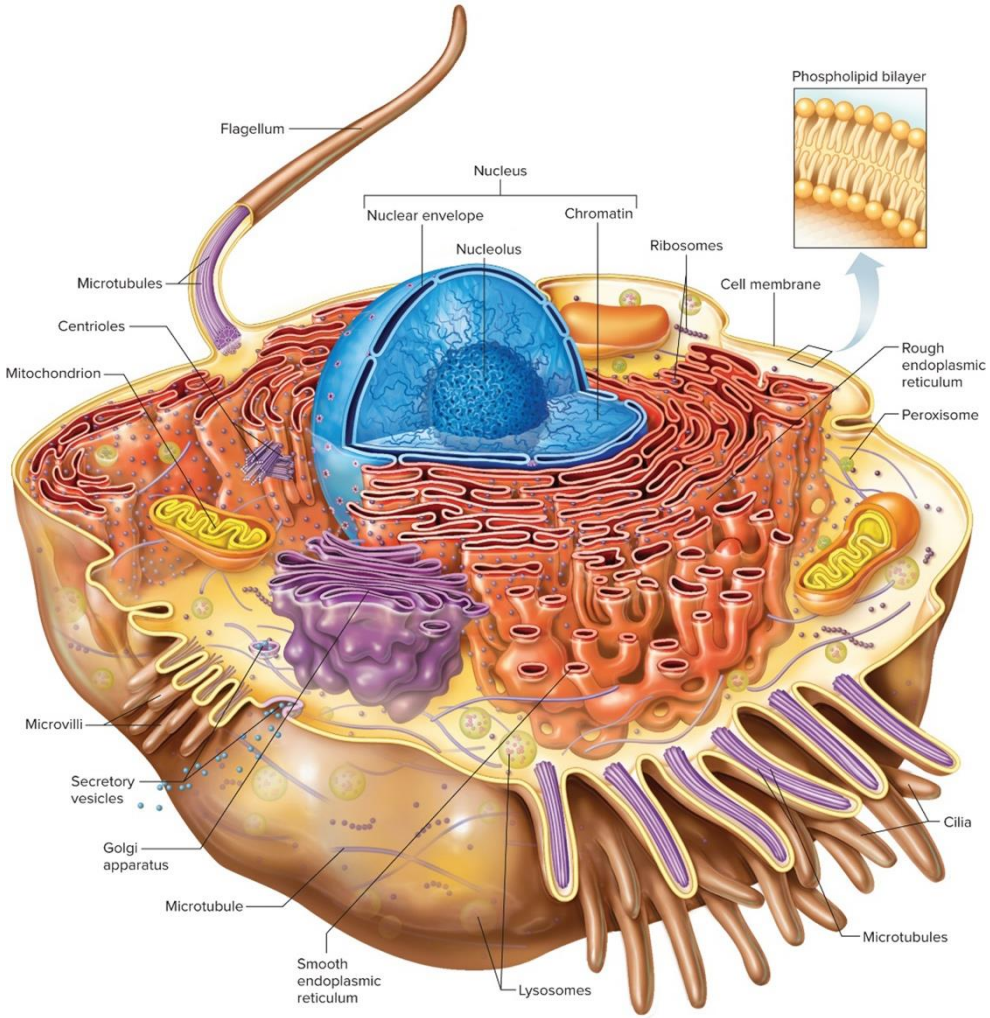
Within the cytoplasm are specialized **organelles** (little organs) that perform specific functions for the cell

Organelles are suspended in a fluid called the **cytosol**

© McGraw Hill

Illustration of a Composite Cell

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Cell Membrane

Cell membrane is also called **plasma membrane**

Boundary that contains the cell contents

Regulates the movement of substances in and out of the cell

Participates in signal transduction, a method of communication with other cells

Helps cells adhere to other cells

General Characteristics:

- Extremely thin, flexible, and elastic
- Selectively permeable – regulates entry/exit of substances
- Has complex surface features, with adaptations to increase surface area

© McGraw Hill

Cell Membrane Structure: Lipids

Composed mainly of lipids and proteins, and some carbohydrates

The basic framework of the cell membrane consists of a **double layer (bilayer) of phospholipids**, with fatty acid tails turned inward and the water-soluble heads facing the surfaces

The phospholipids can move, forming a stable fluid film

Lipid-soluble molecules (respiratory gases, steroid hormones) can pass through the phospholipid portion of the membrane

Cell membrane is impermeable to water-soluble molecules

- Embedded cholesterol molecules stabilize the membrane, and help make it less permeable to water-soluble substances

© McGraw Hill

Cell Membrane Structure: Proteins 1

Many types of **proteins** are found in the cell membrane

Proteins are classified by their relationship to the phospholipid bilayer:

- **Integral:** span width of bilayer; may protrude on 1 or both sides
- **Transmembrane:** integral proteins that protrude on both sides
- **Peripheral:** associate with one side of bilayer

Membrane proteins vary in shape: rodlike, globular, fibrous

Membrane proteins vary in function:

- Some proteins function as **receptors** or **growth factors** on the cell surface, starting signal transduction
- Other proteins transport ions or molecules across cell membrane, such as **ion channels**

© McGraw Hill

Cell Membrane Structure: Proteins 2

Other proteins have carbohydrates attached (glycoproteins) and are used for **cell identification**; this helps identify cells as "self," protecting them from attack by the immune system

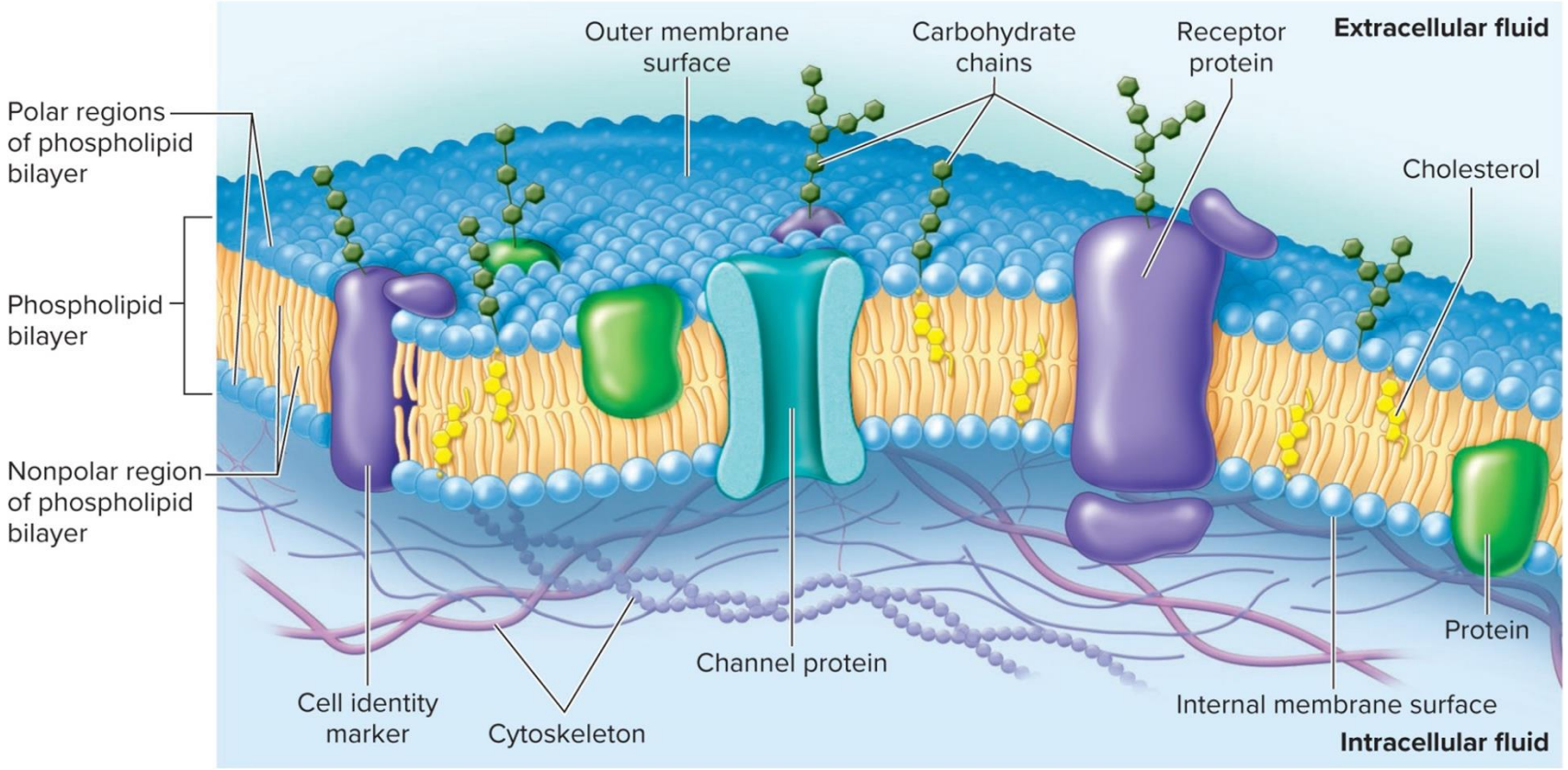
Proteins that protrude into the cell will anchor supportive rods and tubules, forming a **cytoskeleton**

Membrane proteins called **cellular adhesion molecules (CAMs)** help determine a cell's interactions with other cells

© McGraw Hill

Structure of the Plasma Membrane

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



The Cytoplasm

The **cytoplasm** makes up most of cell volume, and consists of a clear liquid (cytosol), a supportive cytoskeleton, and networks of membranes and organelles

Organelles

Ribosomes:

- Tiny, spherical structures composed of RNA and protein
- Provide structural support and enzyme activity for protein synthesis
- Not membranous
- Found in cytoplasm or bound to rough endoplasmic reticulum

© McGraw Hill

Organelles 1

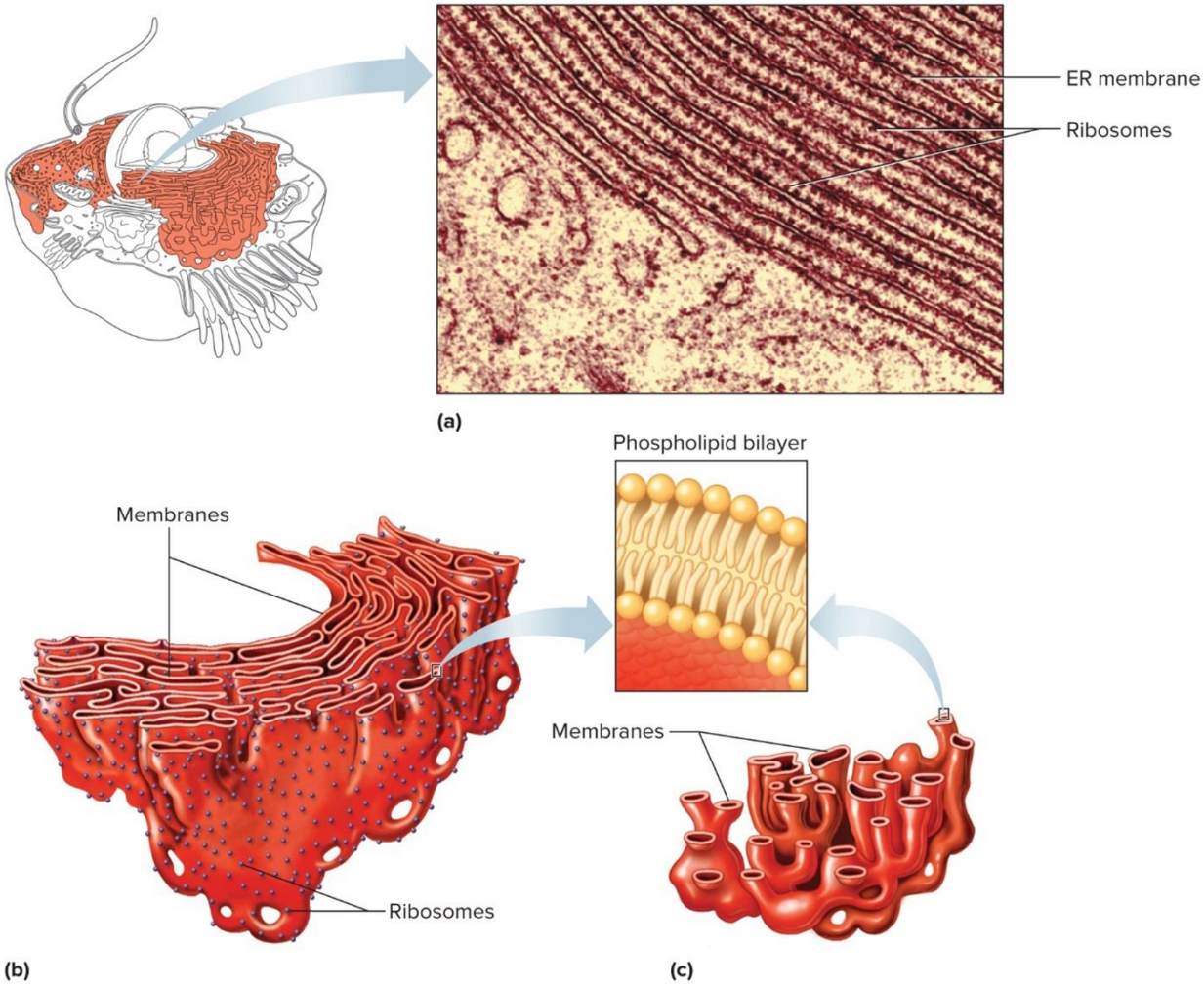
Endoplasmic reticulum (ER):

- Made up of membrane-bound flattened sacs and vesicles
- Functions as a transport network throughout the cell
- 2 types of ER:
  - **Rough ER**: contains ribosomes, and functions in protein synthesis
  - **Smooth ER:** does not contain ribosomes, and functions in lipid synthesis, absorption of fats, and metabolism of drugs

© McGraw Hill

The Endoplasmic Reticulum

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Organelles 2

Vesicles:

- Membranous sacs
- Store or transport substances within or between cells

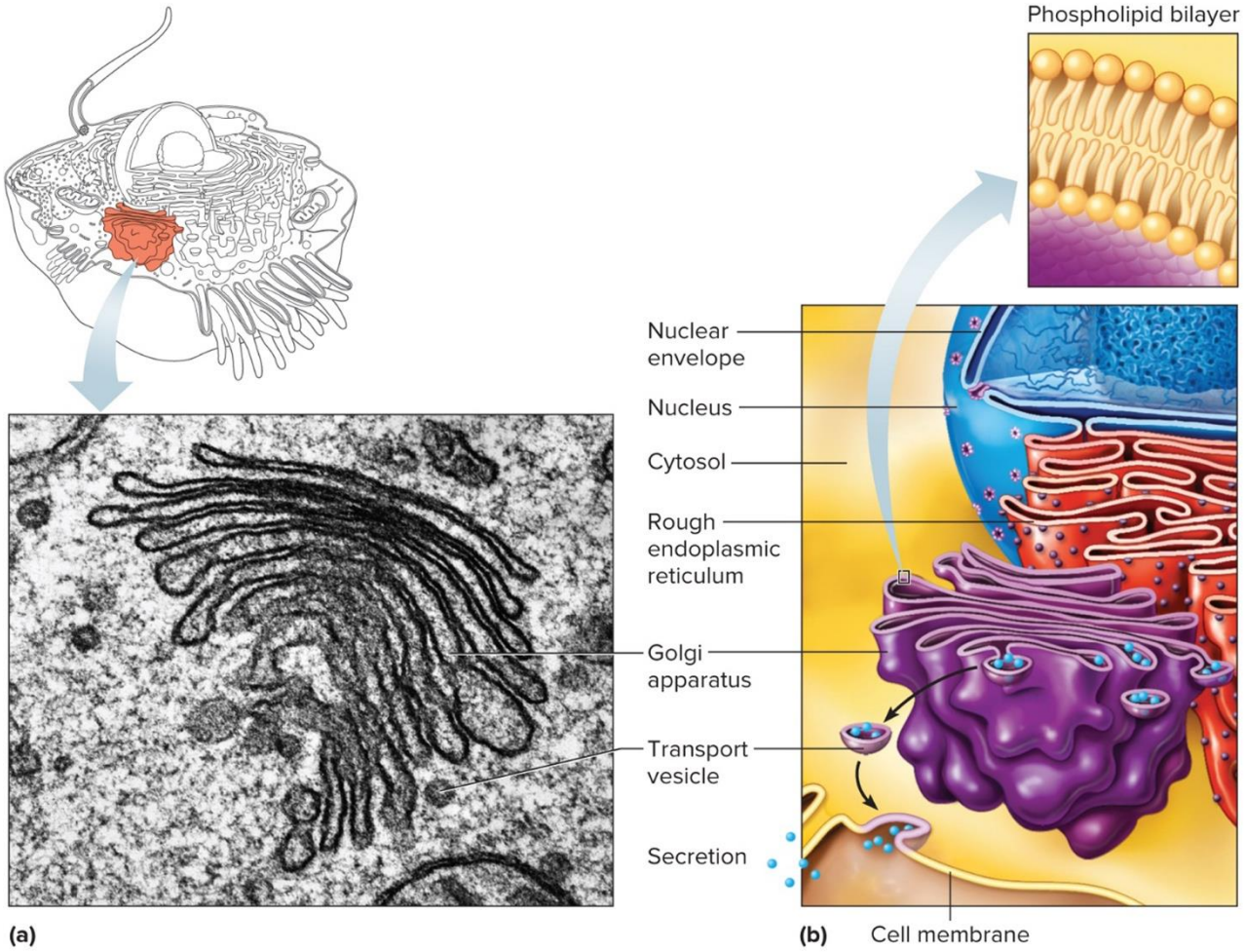
Golgi apparatus:

- Composed of flattened, membranous sacs
- Refines, packages, and transports proteins formed in the rough ER
- Vesicles formed in the ER travel to the Golgi apparatus, which may modify their contents by adding sugar molecules to the proteins, to stabilize their structure or to enable folding.
- A new vesicle pinches off the Golgi apparatus and may then move to the cell membrane to secrete its contents to the outside (exocytosis)

© McGraw Hill

The Golgi Apparatus

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Organelles 3

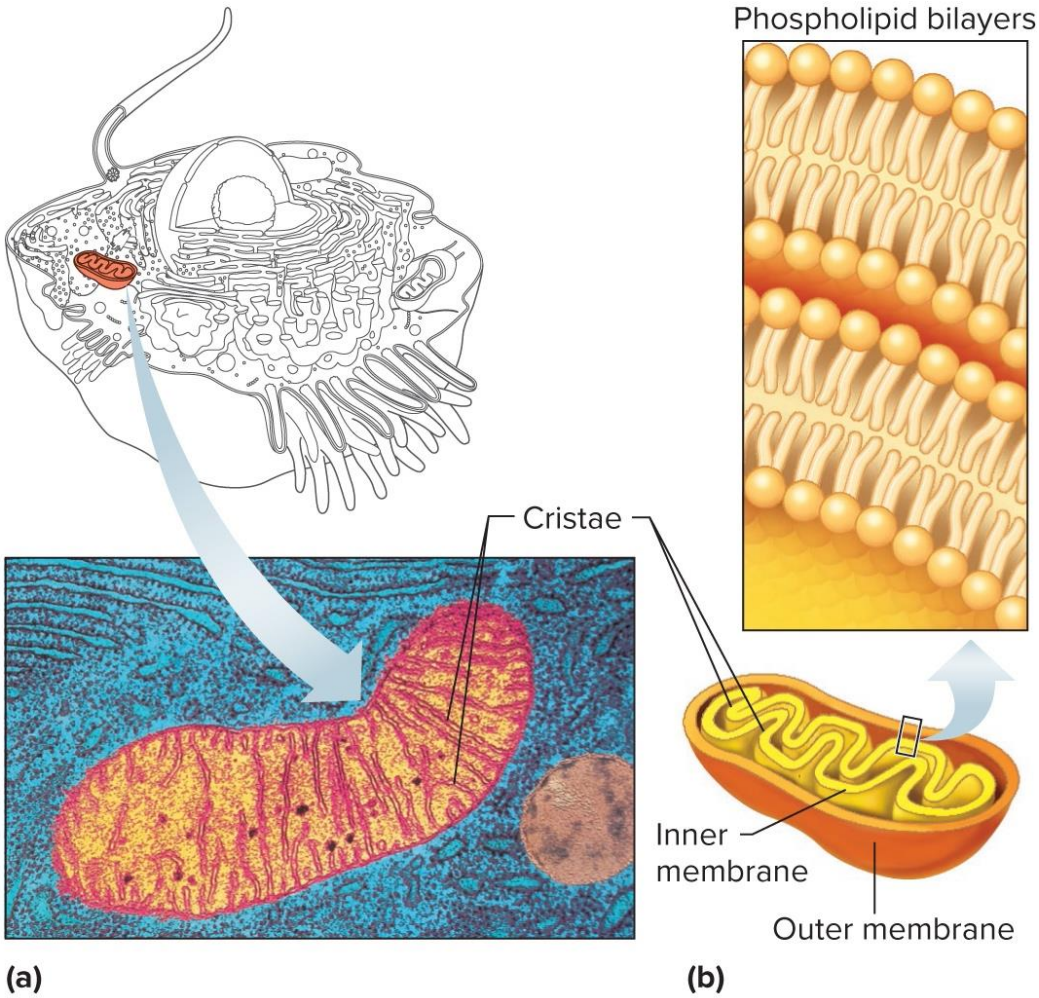
Mitochondria:

- Elongated fluid-filled sacs
- The inner membrane of the mitochondrion is folded into *cristae,* which increase surface area
- House many chemical reactions that extract energy from nutrients (cellular respiration) and produce ATP
- Store the energy in the chemical bonds of ATP
- Very active cells contain thousands of mitochondria
- Mitochondria have their own DNA and reproduce by dividing

© McGraw Hill

Mitochondria

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Organelles 4

Lysosomes:

- Membranous sacs
- Formed by budding off Golgi apparatus
- Contain enzymes that break down nutrients, ingested materials, debris, worn out cell parts, cholesterol (in some cells), toxins, and drugs

Peroxisomes:

- Also membranous sacs
- Contain a different set of enzymes than lysosomes
- Their enzymes function in the breakdown of fatty acids and hydrogen peroxide, and detoxification of alcohol

© McGraw Hill

Other Cellular Structures 1

In the cytoplasm, there are several structures, which are not organelles, but rather part of the **cytoskeleton.**

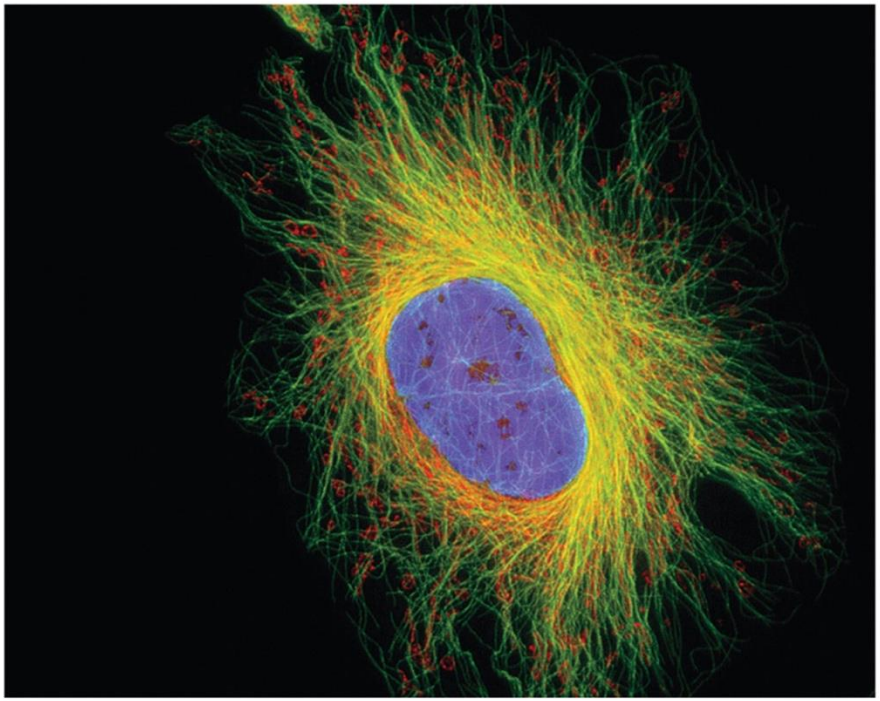
Microfilaments and **microtubules** are thin, threadlike structures that serve as the cytoskeleton of the cell:

- **Microfilaments:** made of the protein actin; cause various cellular movements; group together to form myofibrils in muscle
- **Microtubules**: made of the globular protein tubulin, are attached in a spiral to form a long tube; important in cell division
- **Intermediate fibers:** made of different proteins in different cells, are abundant in skin cells and neurons

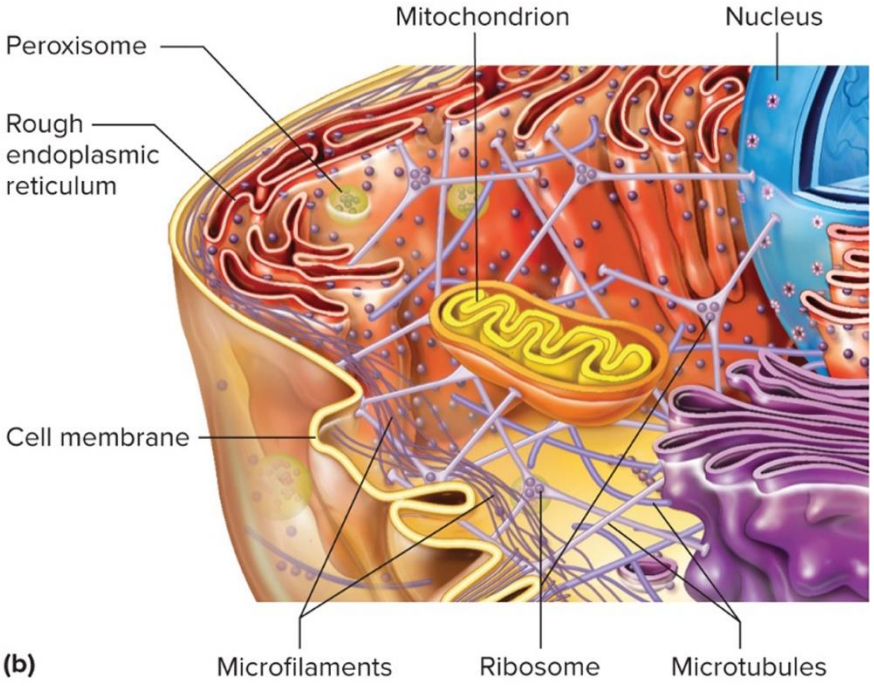
© McGraw Hill

The Cytoskeleton

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a)



(b)

Access the text alternative for slide images.

Other Cellular Structures 2

Centrosome:

A non-membranous structure, made up of two hollow cylinders called c*entrioles,* that function in the distribution of chromosomes during cell division; made of nine groups of three microtubules

Cilia:

Motile extensions from the cell; short cilia are abundant on the free surfaces of certain epithelial cells and move in a wave (respiratory linings, for example) to move fluids or whole cells

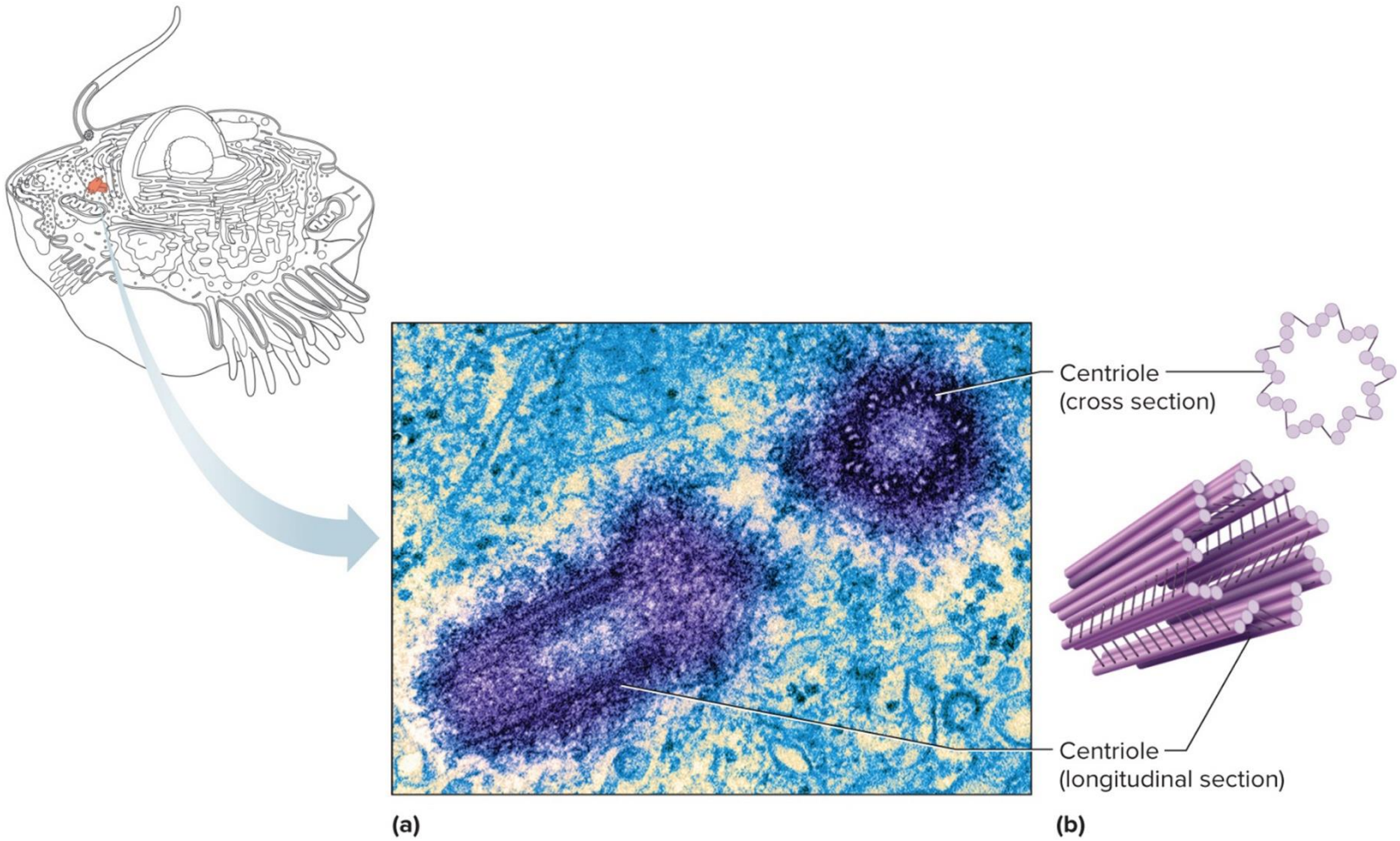
Flagella:

Another type of motile extension from cell; usually a cell only has 1 flagellum; the only human cell with a flagellum is a sperm cell; the flagellum allow the sperm to swim toward the egg cell

© McGraw Hill

The Centrosome (Centrioles)

Copyright © McGraw-Hill Education. Permission required for reproduction or display.

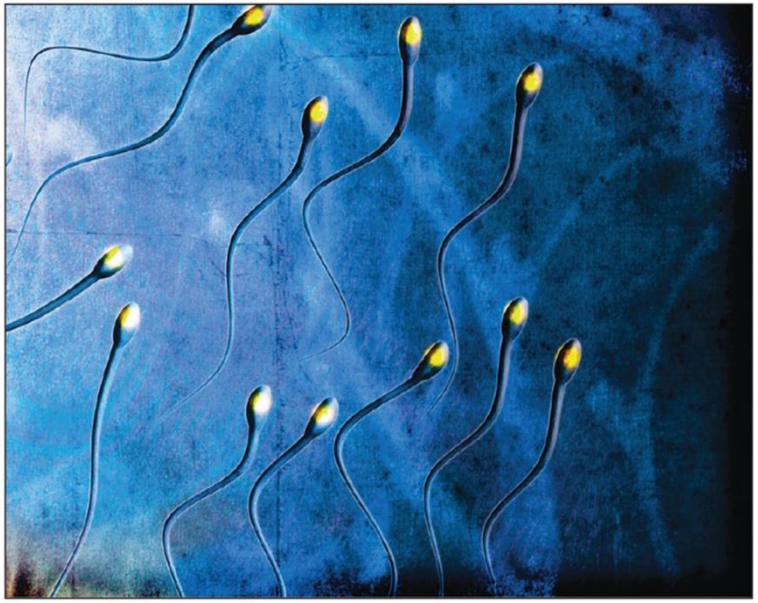


Cilia and Flagella

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



(a)



(b)

Access the text alternative for slide images.

(a): Oliver Meckes/Science Source; (b): Brand X Pictures/Getty Images

The Cell Nucleus 1

The **nucleus** contains genetic material, DNA, which controls cell activities

The fairly large nucleus is surrounded by a double-layered **nuclear envelope,** containing relatively large **nuclear pores** that allow the passage of certain substances

Contains a fluid called **nucleoplasm**

The **nucleolus** is a small, dense body in the nucleus, composed of RNA and protein; it is the site of ribosome production

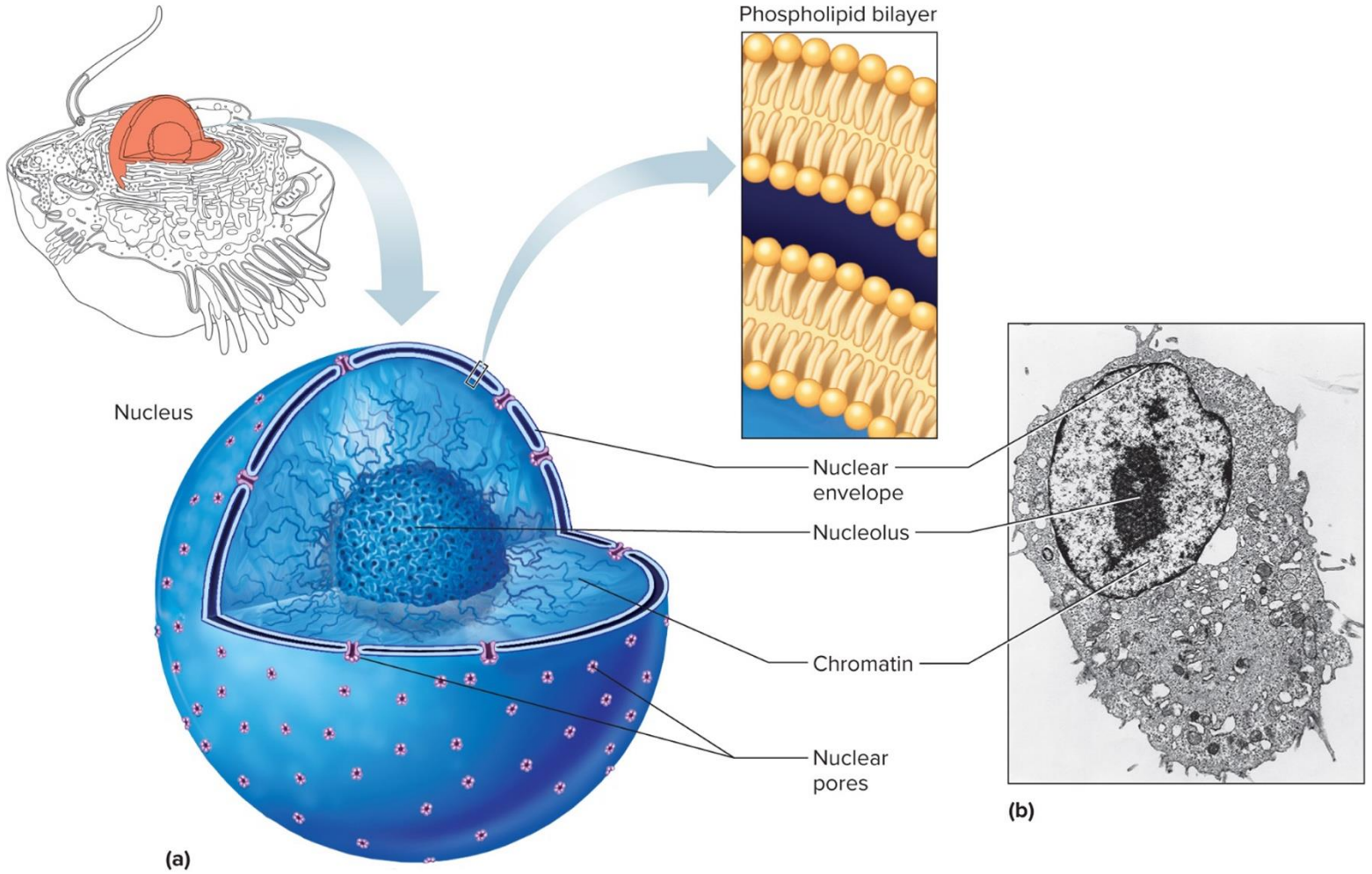
Chromatin consists of loosely coiled fibers of protein and DNA found in the nucleus

Condensed DNA is referred to as **chromosomes;** this form of DNA is present during cell division

© McGraw Hill

The Cell Nucleus 2

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Structures and Functions of Cell Parts 1

TABLE 3.1 Structures and Functions of Cell Parts

Cell Part(s)	Structure	Function
Cell membrane	Membrane composed of protein and lipid molecules	Maintains integrity of cell and controls passage of materials into and out of cell
Ribosomes	Particles composed of protein and RNA molecules	Synthesize proteins
Endoplasmic reticulum	Complex of interconnected membrane-bounded sacs and canals	Transports materials within the cell, provides attachment for ribosomes, and synthesizes lipids
Vesicles	Membranous sacs	Contain and transport various substances
Golgi apparatus	Stack of flattened, membranous sacs	Packages protein molecules for transport and secretion
Mitochondria	Membranous sacs with inner partitions	Release energy from nutrient molecules and change energy into a usable form
Lysosomes	Membranous sacs	Digest worn cellular parts or substances that enter cells

© McGraw Hill

Structures and Functions of Cell Parts 2

TABLE 3.1 Structures and Functions of Cell Parts

Cell Part(s)	Structure	Function
Peroxisomes	Membranous sacs	House enzymes that catalyze diverse reactions, including breakdown of hydrogen peroxide and fatty acids, and alcohol detoxification
Microfilaments and microtubules	Thin rods and tubules	Support the cytoplasm and help move substances and organelles within the cytoplasm
Centrosome	Nonmembranous structure composed of two rodlike centrioles	Helps distribute chromosomes to new cells during cell division
Cilia and flagella	Motile projections attached beneath the cell membrane	Cilia propel fluid over cellular surfaces, and a flagellum enables a sperm cell to move
Nuclear envelope	Double membrane that separates the nuclear contents from the cytoplasm	Maintains integrity of nucleus and controls passage of materials between nucleus and cytoplasm
Nucleolus	Dense, nonmembranous body composed of protein and RNA	Site of ribosome synthesis
Chromatin	Fibers composed of protein and DNA	Contains information for synthesizing proteins

© McGraw Hill

3.3: Movements Into and Out of the Cell

The cell membrane is a **selective barrier,** which controls which substances pass through it

Mechanisms of movement across the membrane may be **passive**, requiring no energy from the cell, or **active**, requiring cellular energy

Examples of **passive transport mechanisms**: diffusion, facilitated diffusion, osmosis, and filtration

Examples of **active transport mechanisms**: active transport, endocytosis, and exocytosis

© McGraw Hill

Passive Mechanisms: Diffusion

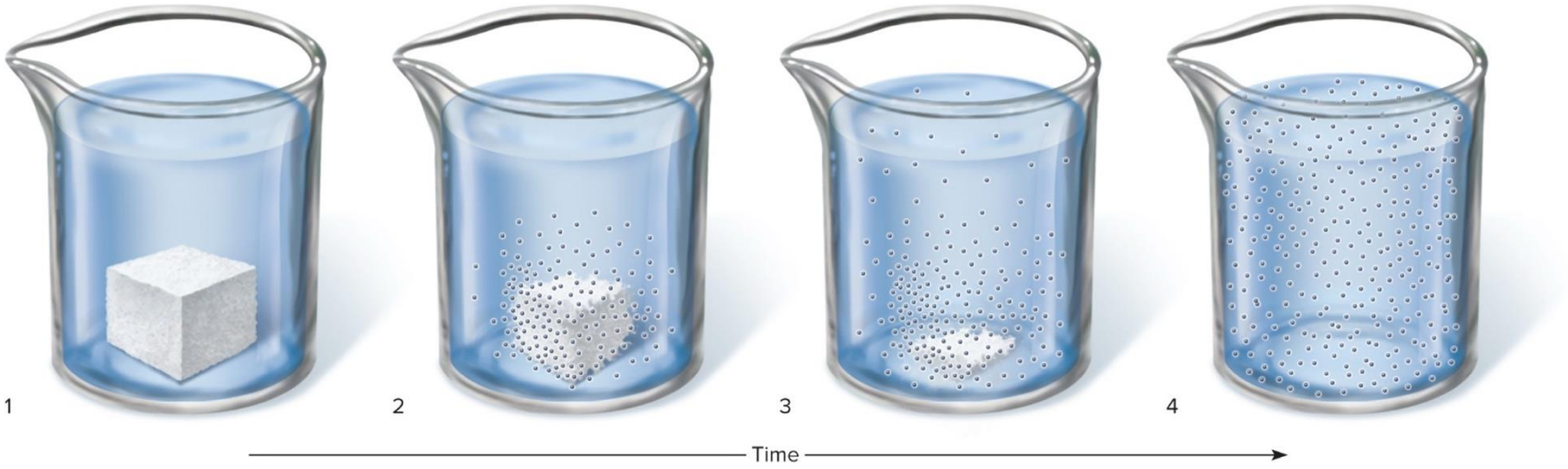
Diffusion:

- Movement of molecules or ions in a liquid or gas from a region of higher concentration to one of lower concentration
- This is referred to as moving **down the concentration gradient**
- Caused by the random motion and collisions of particles
- At **diffusional equilibrium**, particles have become uniformly distributed; they continue to move, but there is no net change in concentration
- Diffusion enables oxygen and carbon dioxide molecules to be exchanged between the air and the blood in the lungs, and between blood and cells
- Diffusion across cell membranes occurs only if cell membrane is permeable to the substance, and there is a concentration gradient
- A sugar cube placed into a glass of water will disperse over time, by the process of diffusion

© McGraw Hill

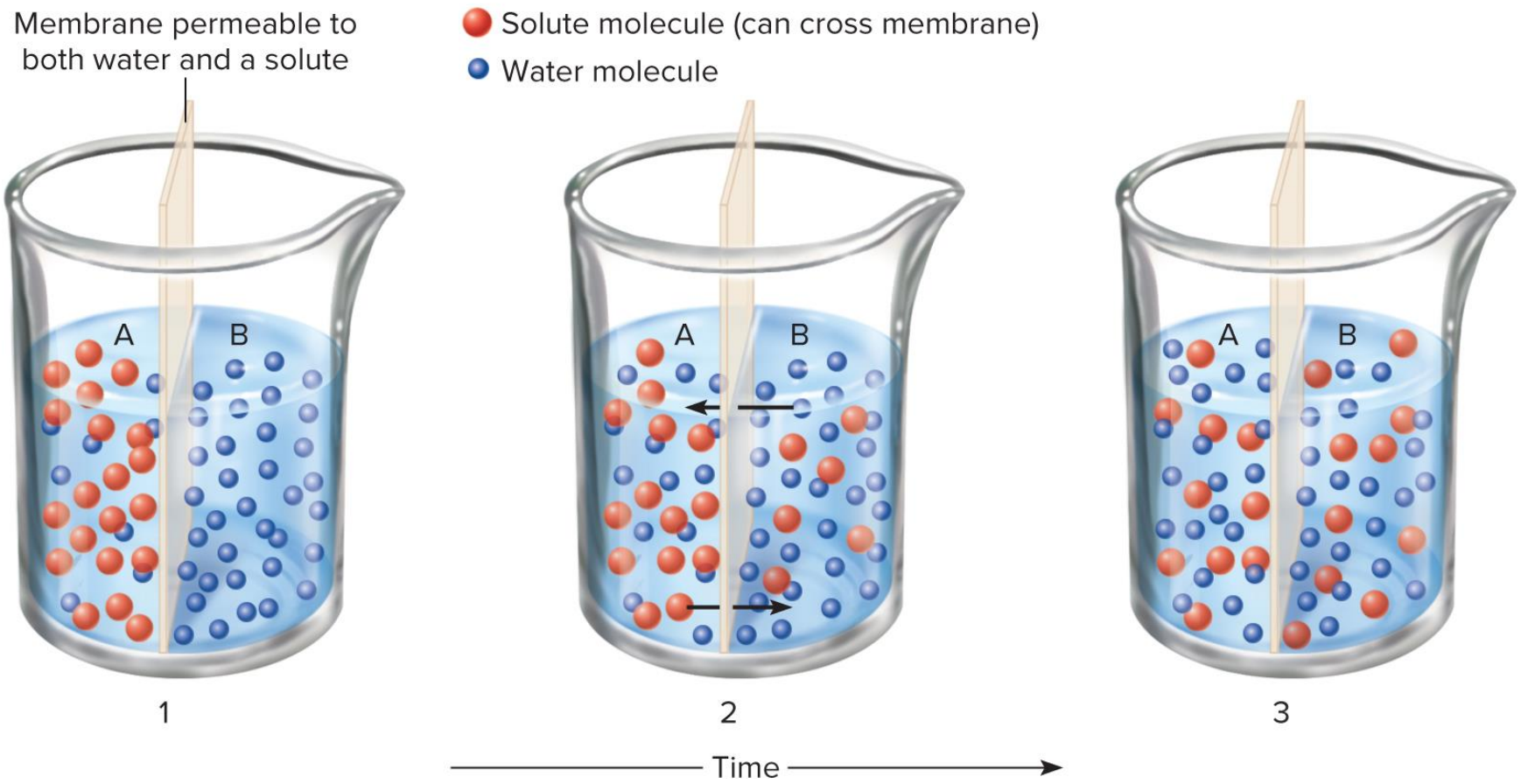
Example of Diffusion:
Dissolving a Sugar Cube in a Glass of Water

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Example of Diffusion Across a Permeable Membrane

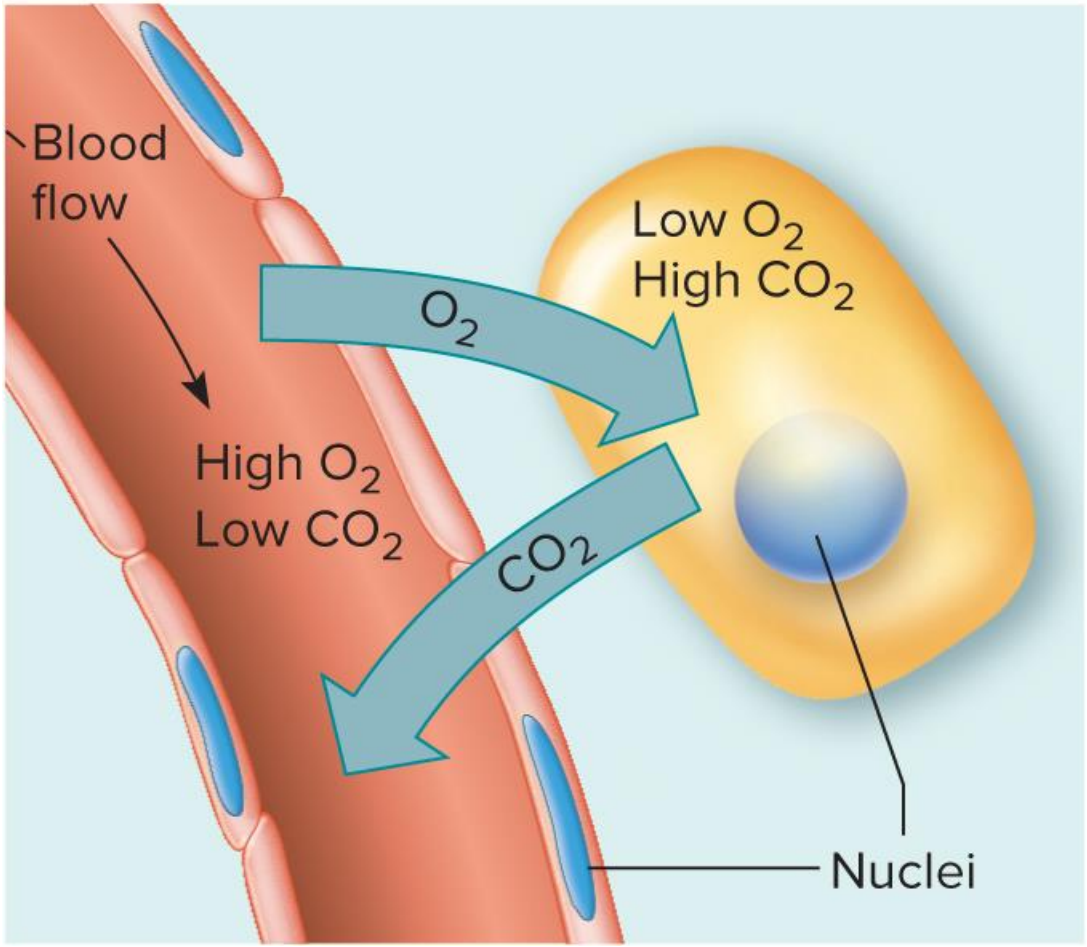
Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Example of Diffusion: Exchange of O_2 and CO_2 Between the Capillaries & Body Cells

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Passive Mechanisms: Facilitated Diffusion

Facilitated diffusion is a method of transport of substances across the cell membrane, using **membrane proteins** to carry the substances across the phospholipid bilayer

One type of facilitated diffusion involves the use of **ion channels** to transport ions across the cell membrane

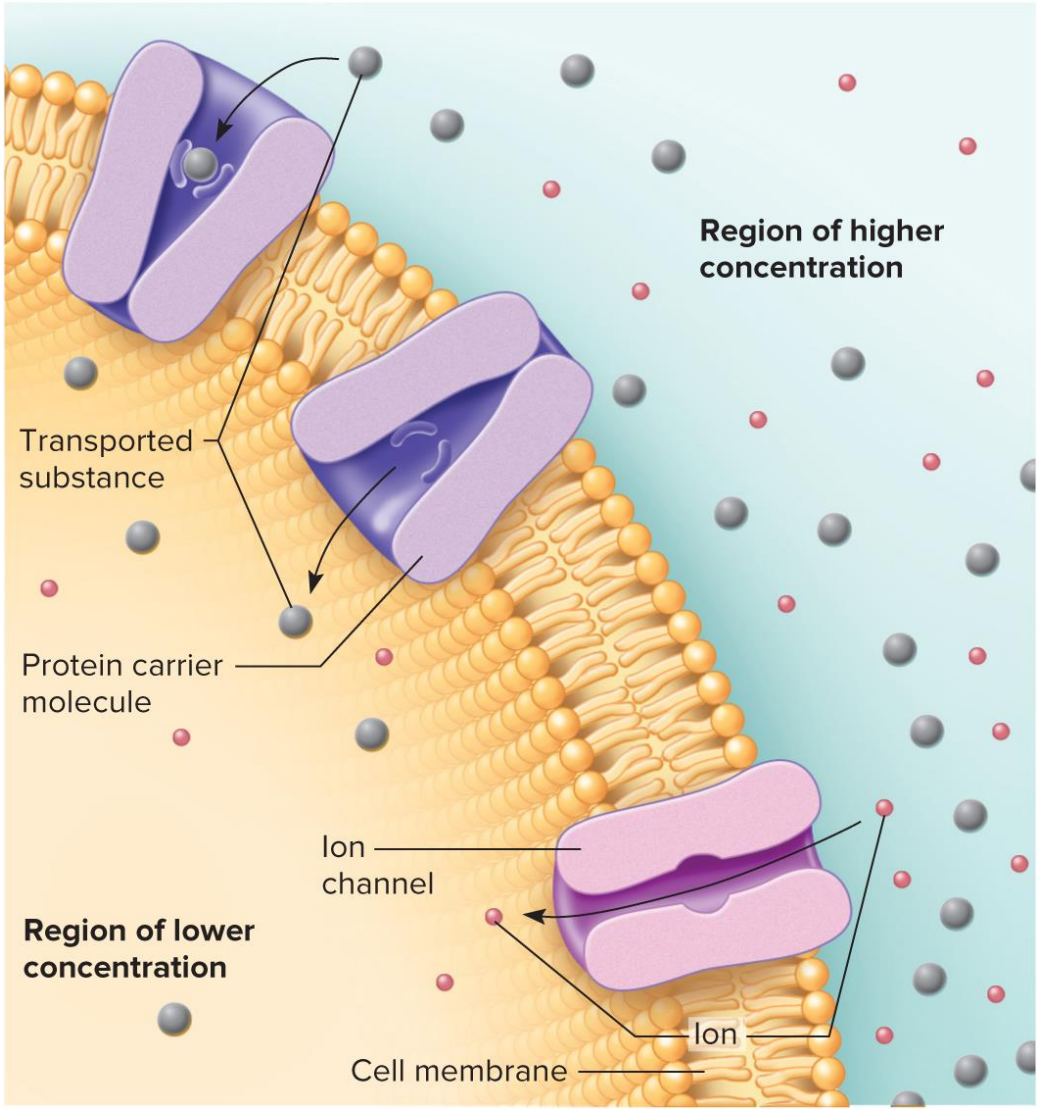
Substances transported by facilitated diffusion, such as glucose and amino acids, cannot pass through the phospholipid bilayer, since they are water-soluble or too large; they require the help of a specific **carrier molecule**

The number of carrier molecules in the cell membrane limits the rate of this process

© McGraw Hill

Facilitated Diffusion

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Passive Mechanisms: Osmosis

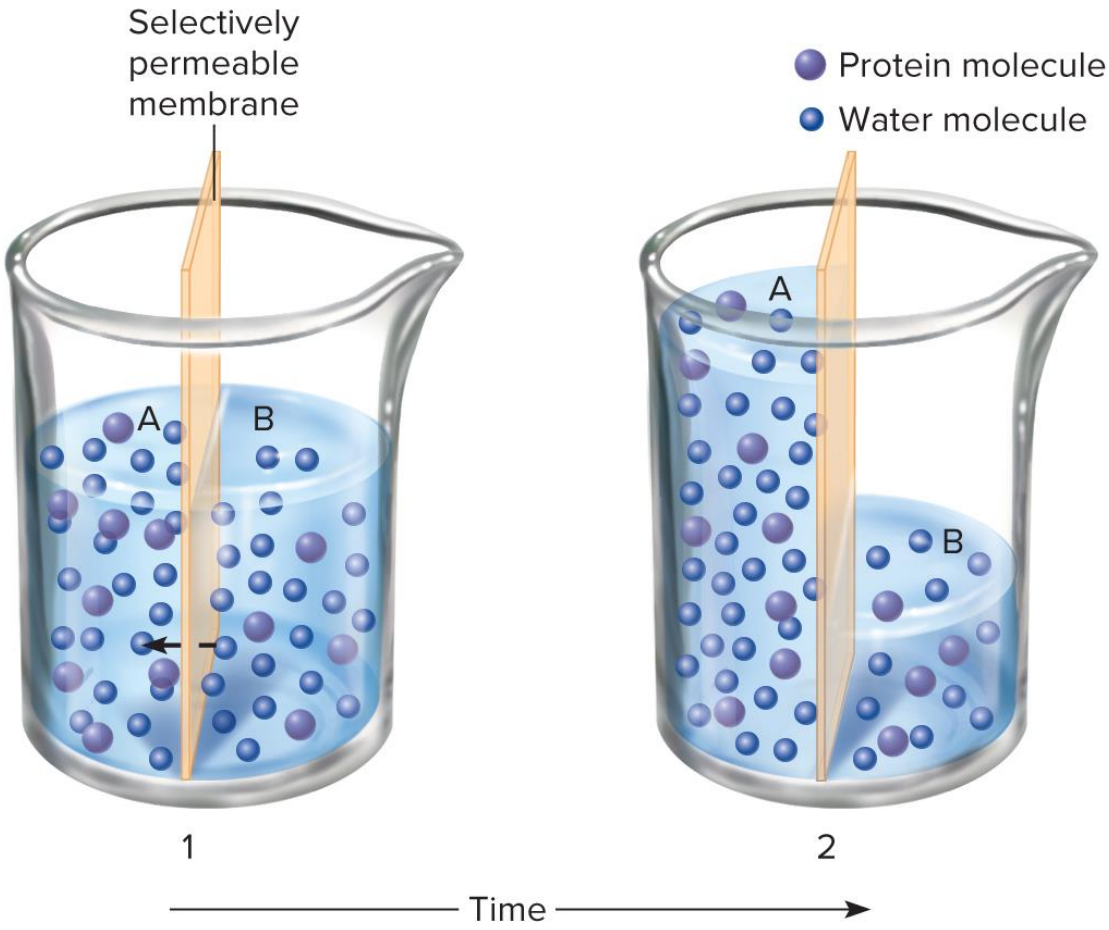
Osmosis:

- Movement of water across a selectively permeable membrane, into an area that contains an impermeant solute
- **Osmosis** is a **special case of diffusion**, in which water moves across a selectively permeable membrane, from an area of greater water concentration (where there is less osmotic pressure and fewer solutes) to an area of lower water concentration (where there is greater osmotic pressure and more solutes)
- During osmosis, water moves from a region of lower solute concentration to a region of higher solute concentration
- The cell membrane is permeable to water but impermeable to the solutes
- **Osmotic pressure** is the pressure needed to lift a volume of water; the greater the concentration of impermeable solutes in a solution, the greater its osmotic pressure

© McGraw Hill

Osmosis

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Tonicity

Tonicity refers to composition of a solution surrounding a cell

The greater the impermeable solute concentration in a solution, the greater its osmotic pressure

Water moves toward solutions with greater osmotic pressure

Cell membranes are usually permeable to water, but not to many solutes, so water equilibrates by osmosis, and makes osmotic pressure equal in the intracellular and extracellular fluids

A solution with the same osmotic pressure as body fluids is called **isotonic**; 0.9% NaCl solution is isotonic to human cells

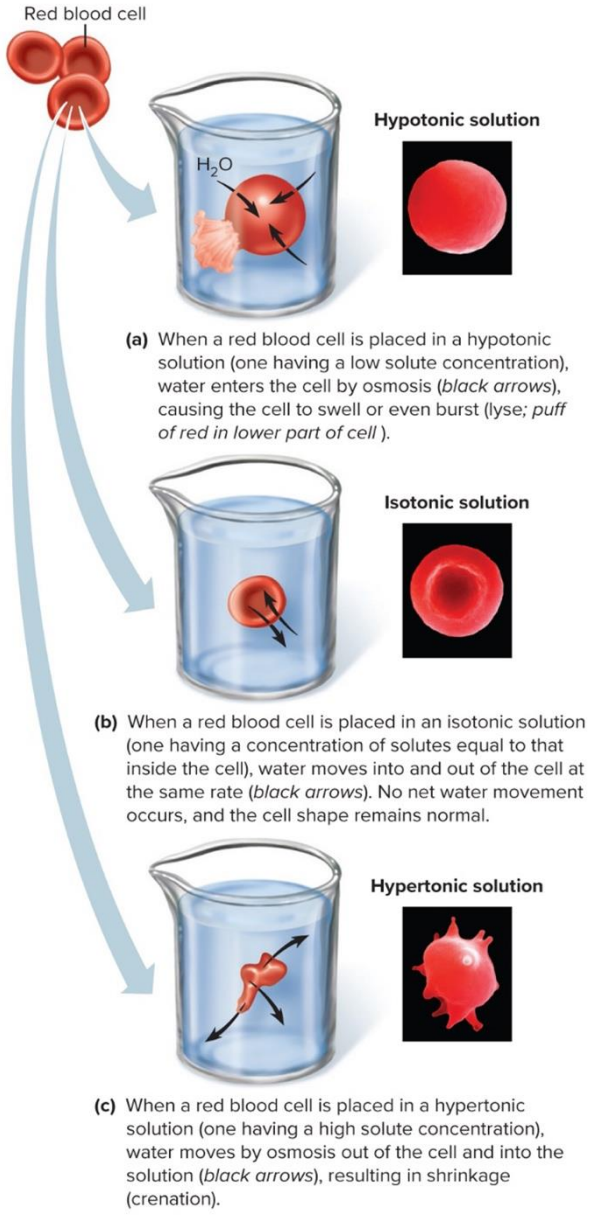
A solution with higher osmotic pressure than body fluids is **hypertonic;** cells placed in a hypertonic solution with lose water and shrink

A solution with lower osmotic pressure than body fluids is **hypotonic;** cells placed in a hypotonic solution will gain water and swell

© McGraw Hill

Copyright © McGraw-Hill Education. Permission required for reproduction or display.

Effects of Hypotonic, Isotonic, and Hypertonic Solutions on Red Blood Cells



(a) When a red blood cell is placed in a hypotonic solution (one having a low solute concentration), water enters the cell by osmosis (*black arrows*), causing the cell to swell or even burst (lyse; *puff of red in lower part of cell*).

(b) When a red blood cell is placed in an isotonic solution (one having a concentration of solutes equal to that inside the cell), water moves into and out of the cell at the same rate (*black arrows*). No net water movement occurs, and the cell shape remains normal.

(c) When a red blood cell is placed in a hypertonic solution (one having a high solute concentration), water moves by osmosis out of the cell and into the solution (*black arrows*), resulting in shrinkage (crenation).

Passive Mechanisms: Filtration

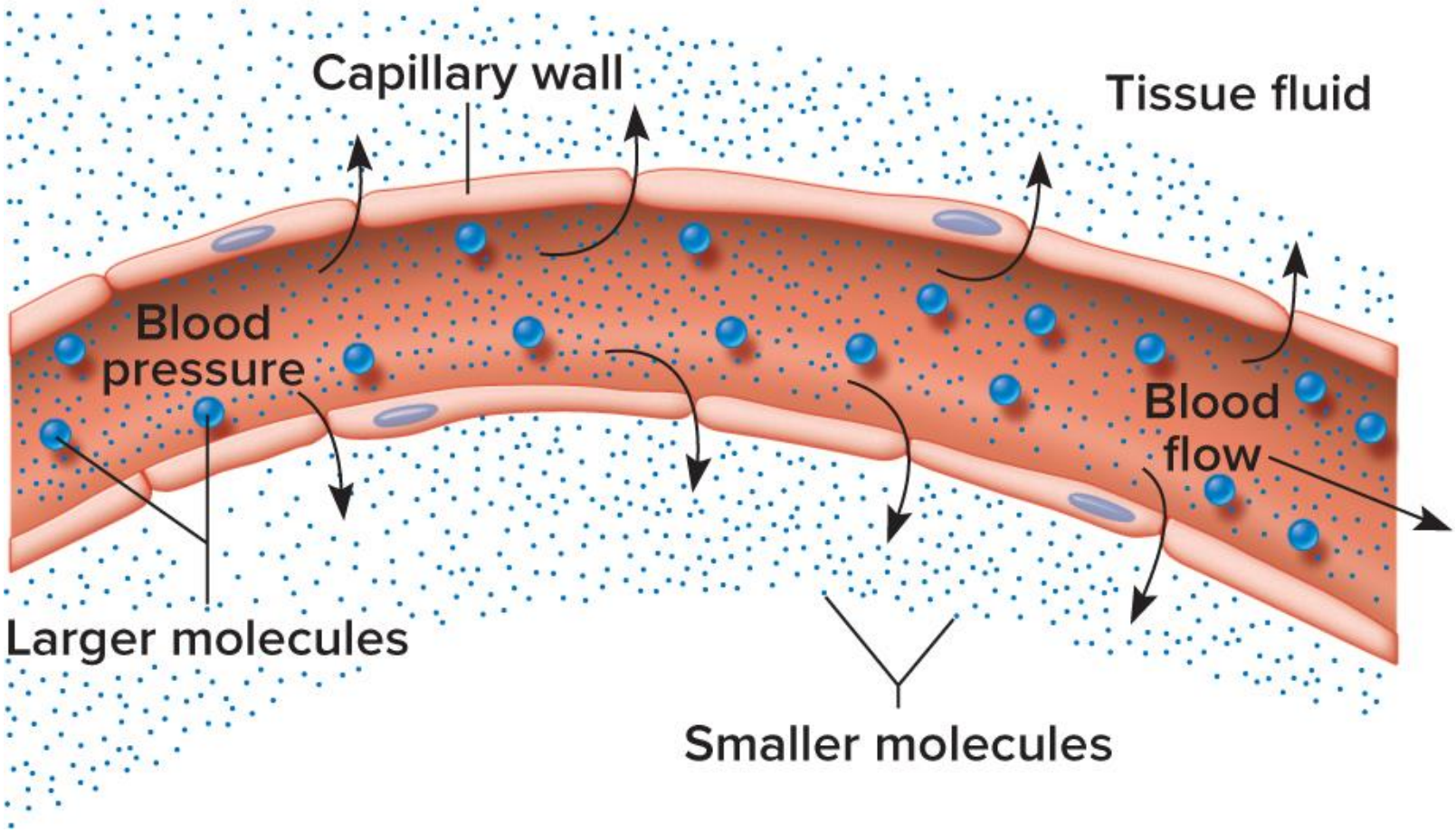
Filtration:

- The process of forcing molecules through membranes due to pressure
- Blood pressure, due to the action of the heart, is a type of hydrostatic pressure, which is used as the force for filtration
- Filtration is used by the body to produce tissue fluid from blood plasma; water and small solutes are sent through the walls of capillaries, to deliver O_2 and nutrients to the cells, while large particles, like plasma proteins, remain in the capillaries
- Particles are generally limited in movement by their size in relation to the size of the openings in the wall of the capillary

© McGraw Hill

Filtration of Small Molecules Through Capillary Walls

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Active Mechanisms: Active Transport

Active mechanisms move substances from a region of lower concentration to a region of higher concentration, and need ATP (adenosine triphosphate) as an energy source

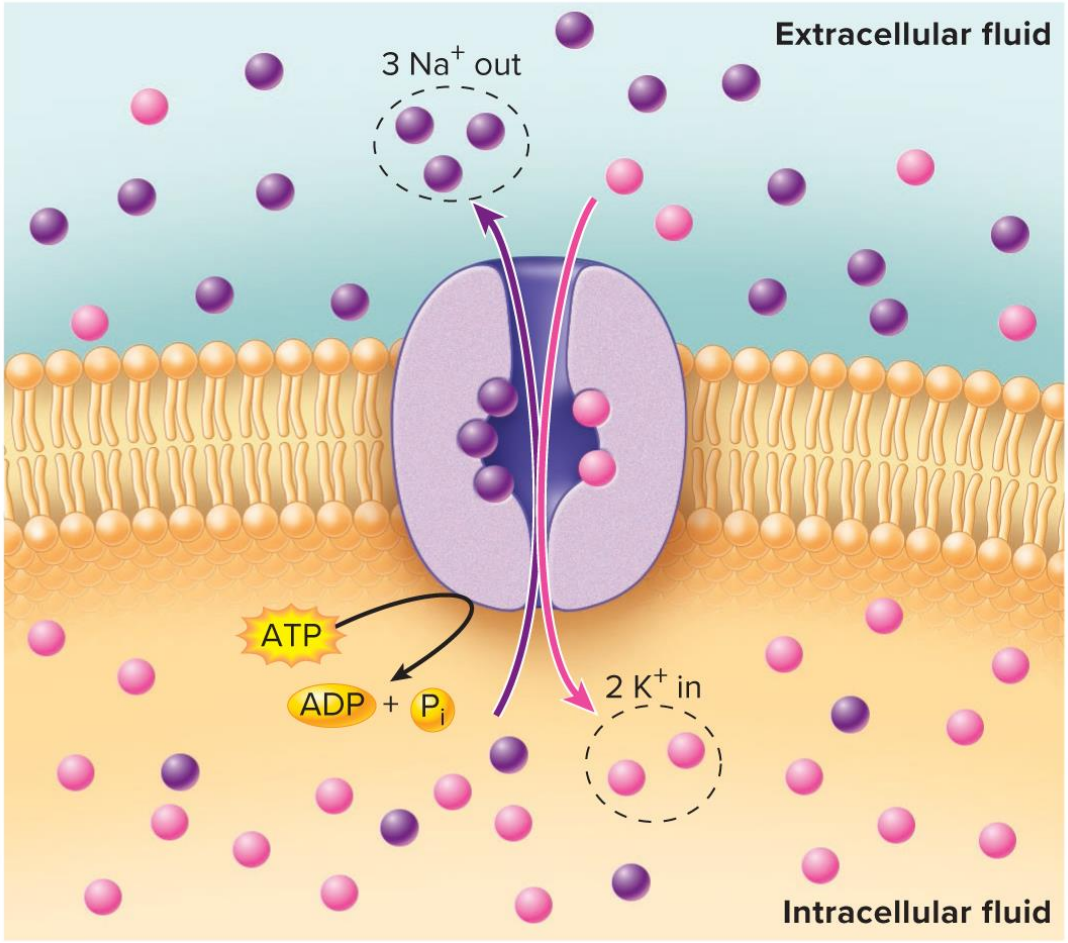
Active Transport:

- Process of moving substances from an area of low concentration to an area of high concentration, through carrier molecules in cell membranes, using ATP energy
- The carrier proteins may also be called **pumps**, since they move substances against the concentration gradient (example: the Na^{+}-K^{+} ATPase pump)
- As much as 40% of a cell's energy may be used to fuel this process
- Substances moved by active transport: Na^{+}, K^{+}, Ca^{+2}, H^{+}, some sugars, and some amino acids

© McGraw Hill

Active Transport: The Na^+-K^+ ATPase Pump

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Active Mechanisms: Endocytosis & Exocytosis

In endocytosis and exocytosis, large substances are moved into or out of a cell without crossing the cell membrane

In **endocytosis**, molecules that are too large to be transported by other means are conveyed inside a **vesicle** that forms from a section of the cell membrane

Exocytosis is the movement of materials out of the cell in a **vesicle** that fuses with the cell membrane and opens up to the outside to secrete the material

© McGraw Hill

Three Types of Endocytosis

Pinocytosis:

- Process by which cells engulf liquids
- “Cell drinking”
- Small indentation in cell membrane surrounds fluid, creating a vesicle

Phagocytosis:

- Process by which the cell takes in solid particles, such as when a white blood cell engulfs a bacterium
- “Cell eating”
- Once the vesicle enters the cell, it combines with a lysosome and the contents are digested by lysosomal enzymes

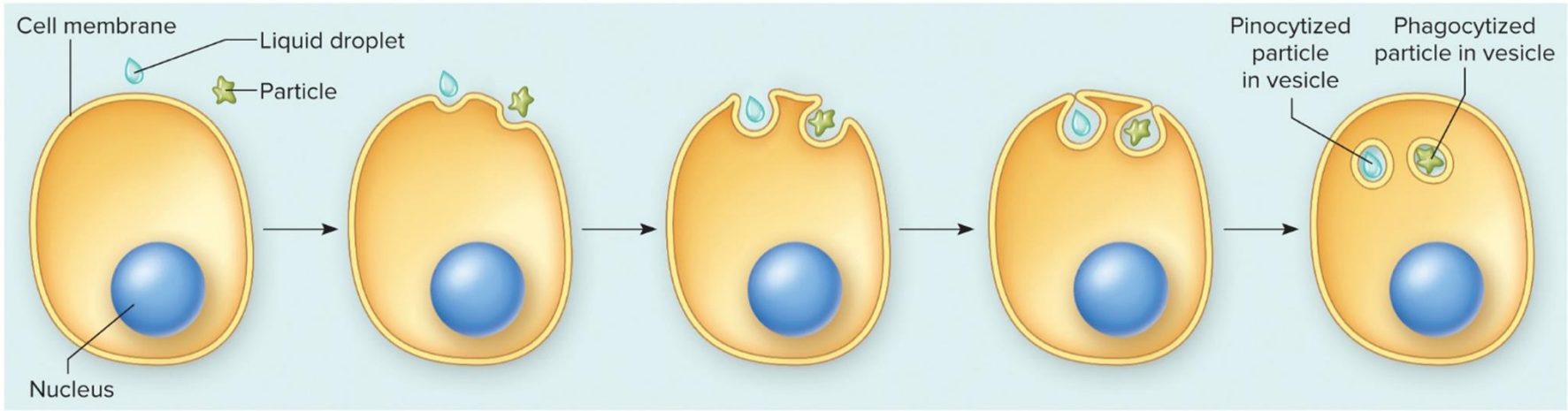
Receptor-mediated endocytosis:

- Process by which the cell takes in very specific molecules (ligands), that bind to specific receptors on the cell membrane to initiate vesicle formation

© McGraw Hill

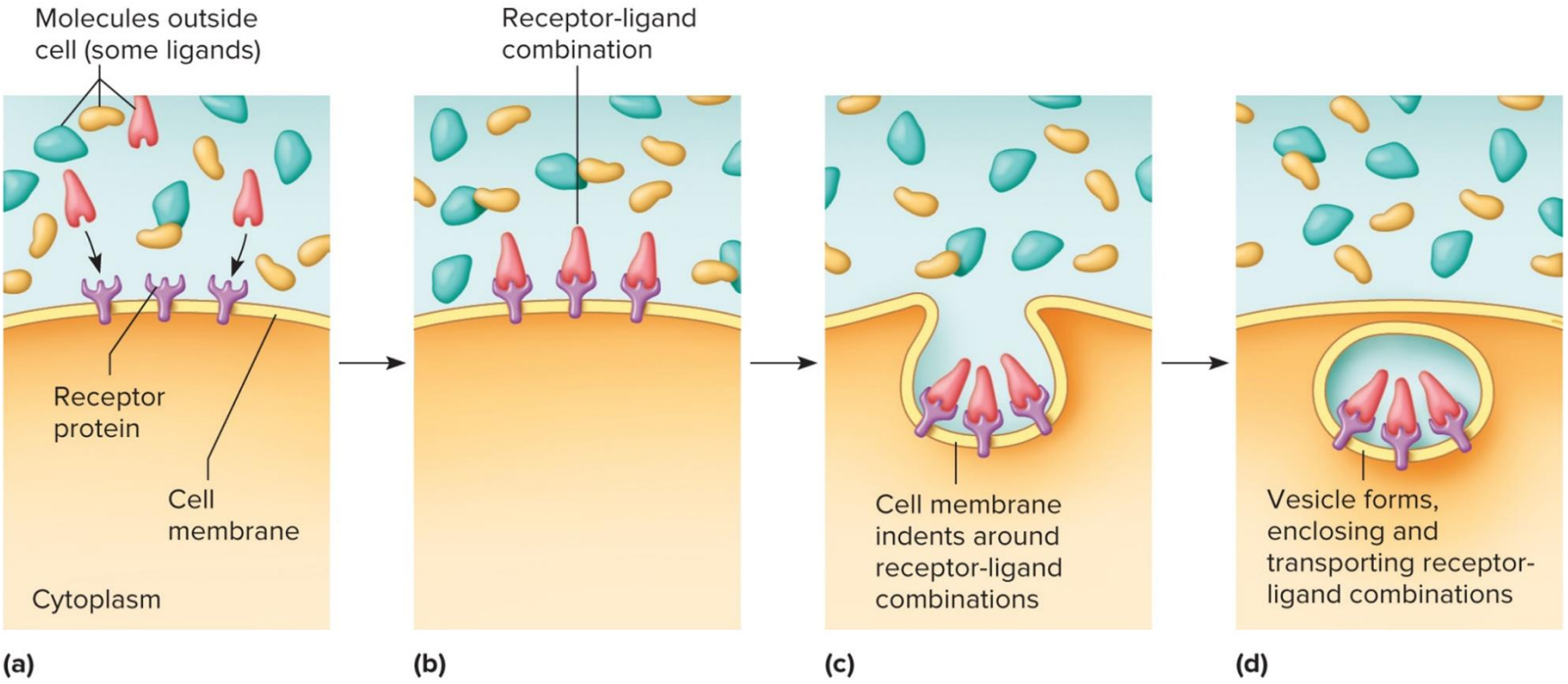
Phagocytosis

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Receptor-Mediated Endocytosis

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Movements Through Cell Membranes: Passive Mechanisms

TABLE 3.2 Movements Through Cell Membranes

Process	Characteristics	Source of Energy	Example
Passive mechanisms			
Diffusion	Molecules move through the phospholipid bilayer from regions of higher concentration to regions of lower concentration.	Molecular motion	Exchange of oxygen and carbon dioxide in the lungs
Facilitated diffusion	Ions move through channels, or molecules move by carrier proteins, across the membrane from a region of higher concentration toward one of lower concentration.	Molecular motion	Movement of glucose through a cell membrane
Osmosis	Water molecules move through a selectively permeable membrane toward the solution with more impermeant solute (greater osmotic pressure).	Molecular motion	Distilled water entering a cell
Filtration	Smaller molecules are forced through porous membranes from regions of higher pressure to regions of lower pressure.	Hydrostatic pressure	Molecules leaving blood capillaries

© McGraw Hill

Movements Through Cell Membranes: Active Mechanisms

TABLE 3.2 Movements Through Cell Membranes

Process	Characteristics	Source of Energy	Example
Active mechanisms			
Active transport	Carrier molecules transport molecules or ions through membranes from regions of lower concentration toward regions of higher concentration.	Cellular energy (ATP)	Movement of various ions, sugars, and amino acids through membranes
Endocytosis			
Pinocytosis	Membrane engulfs droplets containing dissolved molecules from surroundings.	Cellular energy	Uptake of water and solutes by all body cells
Phagocytosis	Membrane engulfs particles from surroundings.	Cellular energy	White blood cell engulfing bacterial cell
Receptor-mediated endocytosis	Membrane engulfs selected molecules combined with receptor proteins.	Cellular energy	Cell removing cholesterol molecules from its surroundings
Exocytosis	Vesicle fuses with membrane and releases contents outside of the cell.	Cellular energy	Neurotransmitter release

© McGraw Hill

3.4: The Cell Cycle

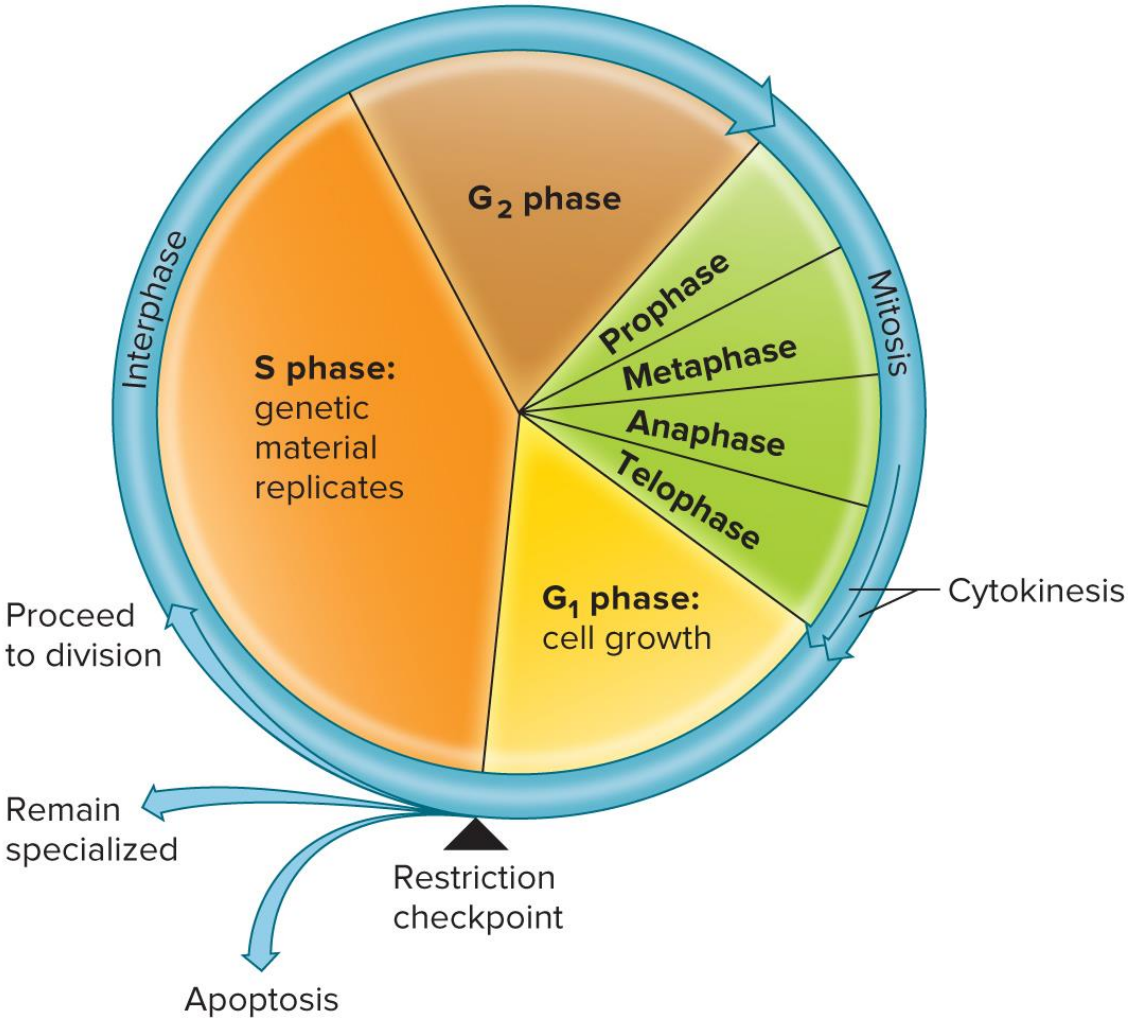
Cell Cycle:

- The series of changes a cell undergoes from the time it is formed until it divides
- Main phases are **interphase**, **mitosis**, and **cytokinesis** (division of the cytoplasm)
- Daughter cells might then undergo changes to become specialized
- Whether the cell cycle progresses at certain times, called **checkpoints,** is controlled by interaction of special proteins
- A r**estriction checkpoint** determines fate of cell: to continue cell cycle and divide, to enter a non-dividing stage as a specialized cell, or to die
- Most cells do not divide continually. Cells have a maximum number of times they can divide, because of built-in “clocks” (telomeres) on the tips of chromosomes, which shorten with each cell division

© McGraw Hill

Phases of the Cell Cycle

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Interphase

Interphase:

- Phase of the cell cycle, before cell division begins, in which the cell grows and synthesizes new molecules, membranes, DNA, and organelles
- This is a time of great synthetic activity, rather than a time of rest
- During the G_1 and G_2 ("gap" or "growth") phases of interphase, the cell grows, and structures other than DNA are duplicated
- During the S ("synthesis") phase of interphase, the DNA of the cell is replicated in preparation for cell division

© McGraw Hill

Cell Division

2 types of cell division:

Meiosis:

- Only used for sperm & egg cell production
- Ensures that mature gametes have ½ the normal number of chromosomes as normal body cells

Cell Division (Mitosis + Cytokinesis):

- More common type of cell division, used to increase number of cells
- Mitosis is division of the nucleus
- Cytokinesis is the division of the cytoplasm
- Regulated carefully, so that each of two daughter cells receives an exact copy of the original cell's genetic material (DNA)

© McGraw Hill

Stages of Mitosis 1

Mitosis is described as a series of four stages, but the process is actually continuous:

1. **Prophase:**
    - The first stage of mitosis
    - DNA condenses into visible chromosomes (each consisting of two chromatids connected by a centromere)
    - Centrioles migrate to opposite poles
    - Microtubules of the cytoskeleton organize into spindle fibers
    - The nuclear membrane and nucleolus disassemble

© McGraw Hill

Stages of Mitosis 2

2. **Metaphase:**
   - Spindle fibers attach to centromeres on the chromosomes
   - Chromosomes randomly align midway between centrioles

3. **Anaphase:**
   - Sister chromatids are pulled apart
   - Chromatids are now considered individual chromosomes
   - Chromatids are pulled along the shortening spindle fibers toward opposite centrioles

© McGraw Hill

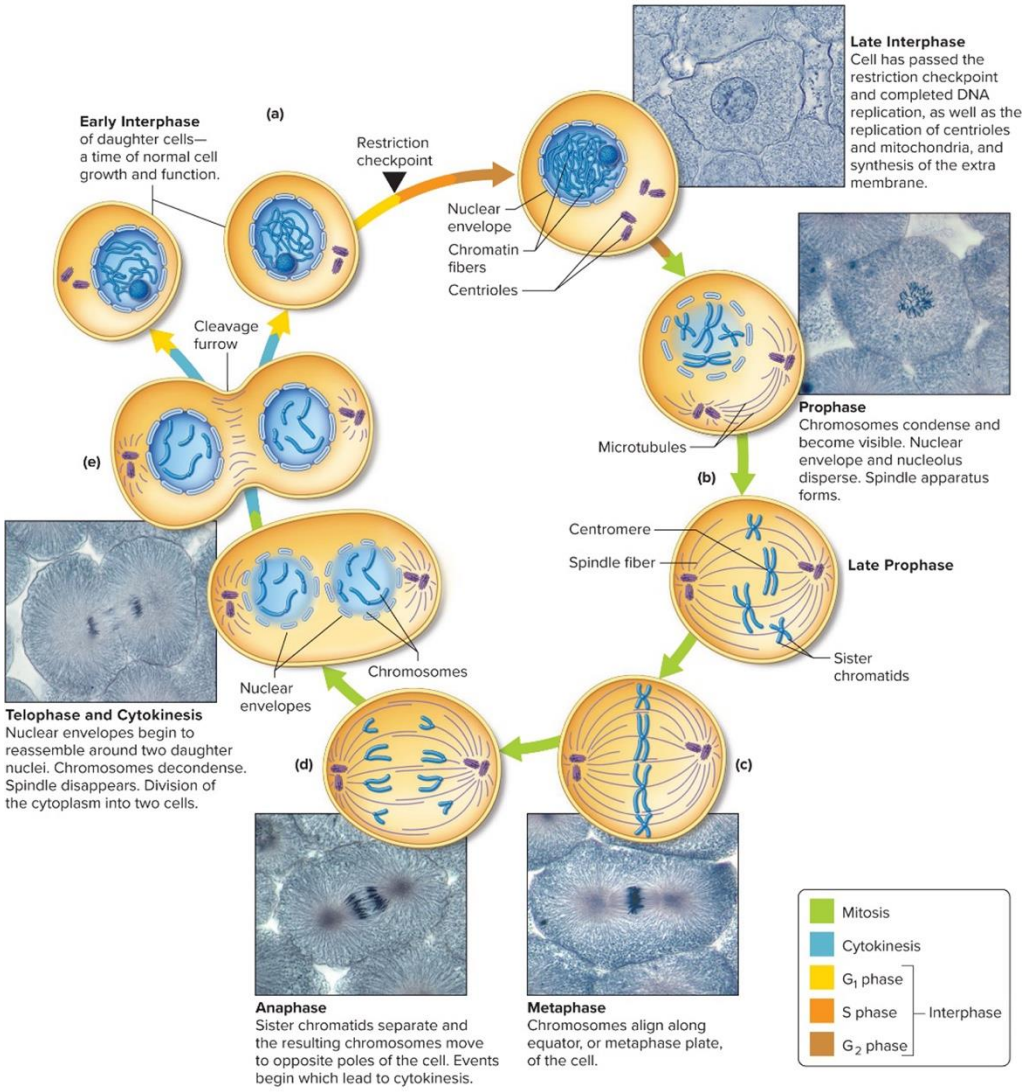
Stages of Mitosis 3

4. **Telophase:**
    - The final stage of mitosis
    - Begins when the chromosomes have completed their migrations to opposite sides
    - A nuclear envelope and nucleolus assemble for each forming cell
    - The spindle fibers disassemble
    - The chromosomes unwind, and take back their chromatin form

© McGraw Hill

Stages of Mitosis 4

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Cytokinesis (Cytoplasmic Division)

Cytokinesis:

- Cytoplasmic division
- Begins during anaphase of mitosis, when cell membrane constricts around middle of cell
- Constriction, called the **cleavage furrow**, continues throughout telophase; it eventually pinches the daughter cells apart
- **Contractile ring** of microfilaments attaches to inside of cell membrane; it divides the cytoplasm
- The two daughter cells may have slightly different amounts of cytoplasm and organelles, but they share identical genetic information

© McGraw Hill

Cell Differentiation

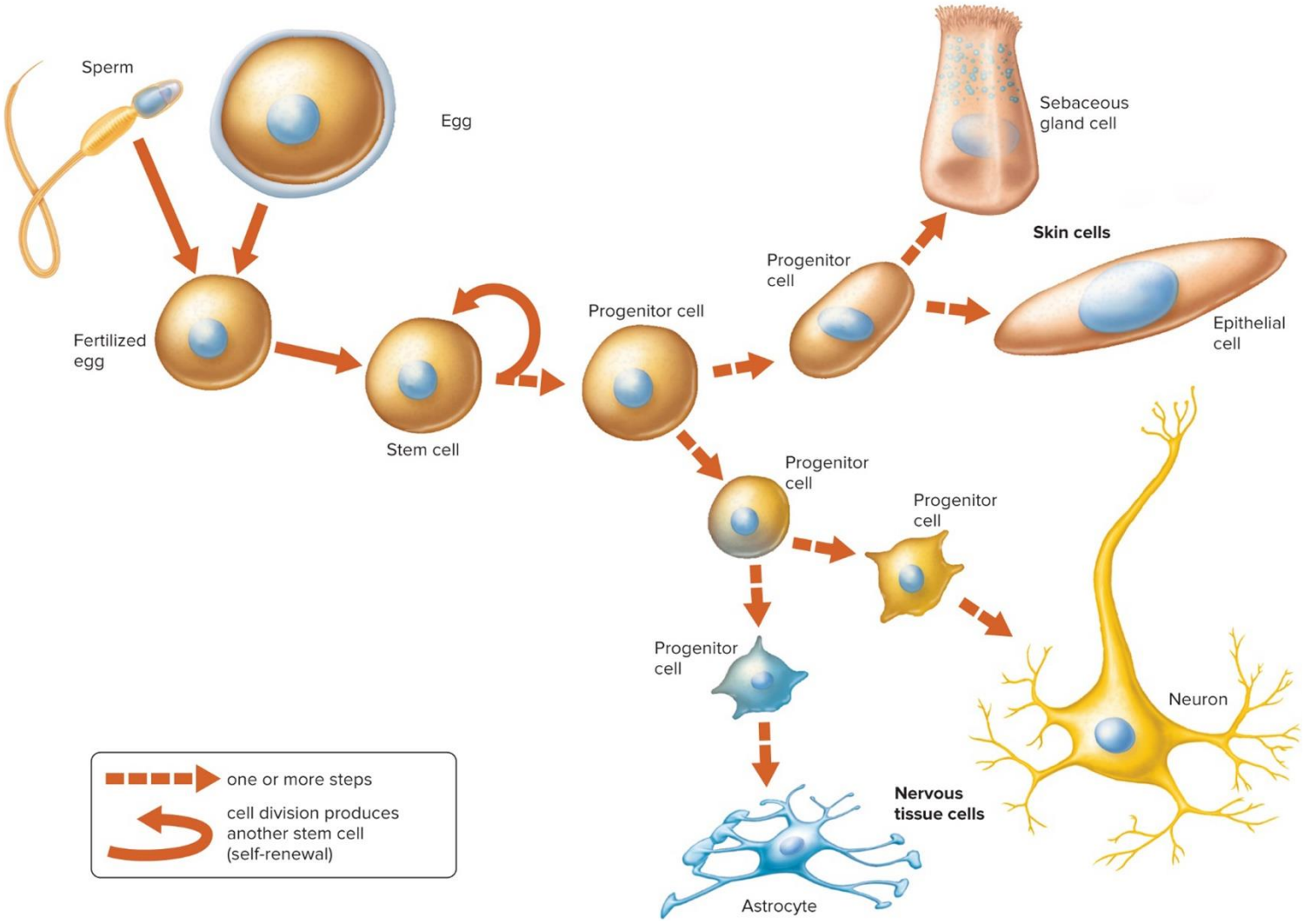
Differentiation:

- The process by which a cell develops/specializes into a specific type of cell with specialized functions
- Humans have >290 types of differentiated cells
- Cell differentiation allows cells to specialize by using different parts of the complete genome that is present in each cell; in each type of cell, some genes are “turned on” while others are “turned off”
- **Stem cells** retain the ability to divide without specialization; their presence in the cell allows for continuous growth and renewal
- **Progenitor cells** are daughters of stem cells that are partially specialized
- Stem and progenitor cells allow cells to retain the ability to produce cells that will become the differentiated cells in each area of the body

© McGraw Hill

Stem and Progenitor Cells

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Cell Death

Not all cells divide or differentiate; some die

Apoptosis is a form of programmed cell death that is a normal part of development, rather than from injury or disease

Removes overgrown tissues, damaged cells, extra cells in fetus

Steps of apoptosis:

- Cell becomes rounded and bulges
- Nuclear membrane breaks down
- Chromatin condenses and enzymes cut up the chromosomes
- Cell shatters into many membrane-bound pieces
- Scavenger cells engulf and destroy the fragments

© McGraw Hill



Because learning changes everything.®

www.mheducation.com

© 2021 McGraw Hill. All rights reserved. Authorized only for instructor use in the classroom.
No reproduction or further distribution permitted without the prior written consent of McGraw Hill.

Chapter 4
Cellular Metabolism

HOLE'S ESSENTIALS OF HUMAN ANATOMY & PHYSIOLOGY

Charles J. Welsh

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



© 2021 McGraw Hill. All rights reserved. Authorized only for instructor use in the classroom.
No reproduction or further distribution permitted without the prior written consent of McGraw Hill.

4.1: Introduction

A living cell is the site of enzyme-catalyzed metabolic reactions that maintain the life of the cell and the body

Enzymes allow metabolic reactions to proceed quickly enough to maintain life

A constant supply of energy is needed for the body's metabolism

Information from DNA is required to construct proteins, including the enzymes necessary for reactions

Cellular Metabolism is the group of chemical reactions that acquire, store, and release energy in the cells of the body

Energy is derived from chemical bonds in nutrient molecules obtained in the diet

© McGraw Hill

4.2: Metabolic Reactions

Metabolic reactions are of two types:

- **Anabolic reactions (anabolism):** larger molecules are synthesized from smaller ones; requires energy
- **Catabolic reactions (catabolism):** larger molecules are broken down, or decomposed, into smaller ones; releases energy (40%) and heat (60%)

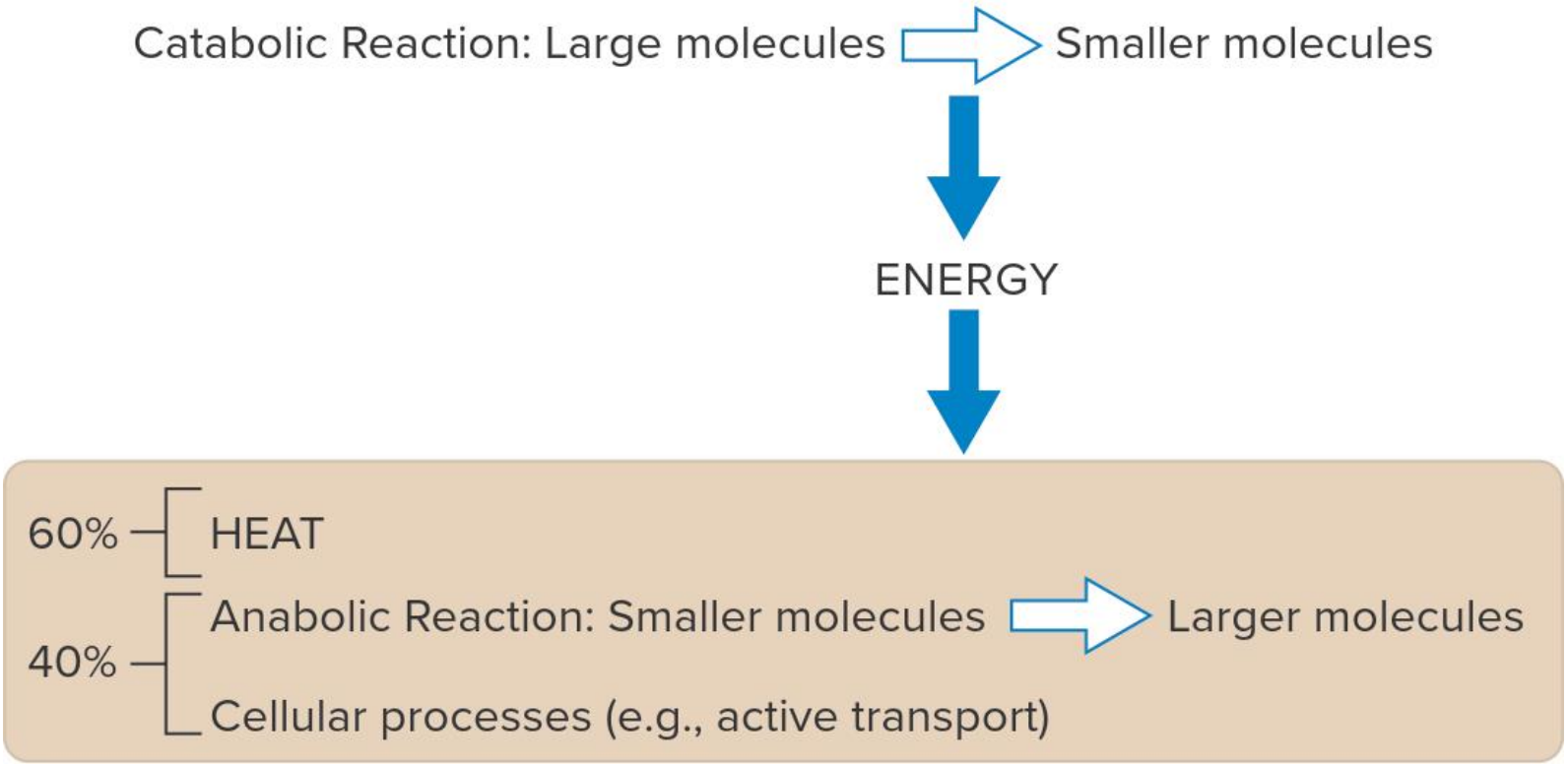
The reactions of metabolism are often reversible.

Anabolism + Catabolism = Metabolism

© McGraw Hill

Catabolic Reactions Produce Energy & Heat

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Anabolism 1

Anabolism provides the biochemicals for growth and repair

Many of these reactions occur by **dehydration synthesis**, removing a molecule of water to join two smaller molecules (represented as A and B):

$$A—OH + H—OB \rightarrow A—OB + H_2O$$

Example: When 2 monosaccharides (simple sugars) are bound together to form a disaccharide, a H (hydrogen) atom is removed from one sugar, while an OH (hydroxyl) group is removed from the other $H + OH \rightarrow H_2O$, and the 2 sugars are chemically bound together in the process. The removal of a water molecule gives this reaction the name, “dehydration synthesis.”

© McGraw Hill

Anabolism 2

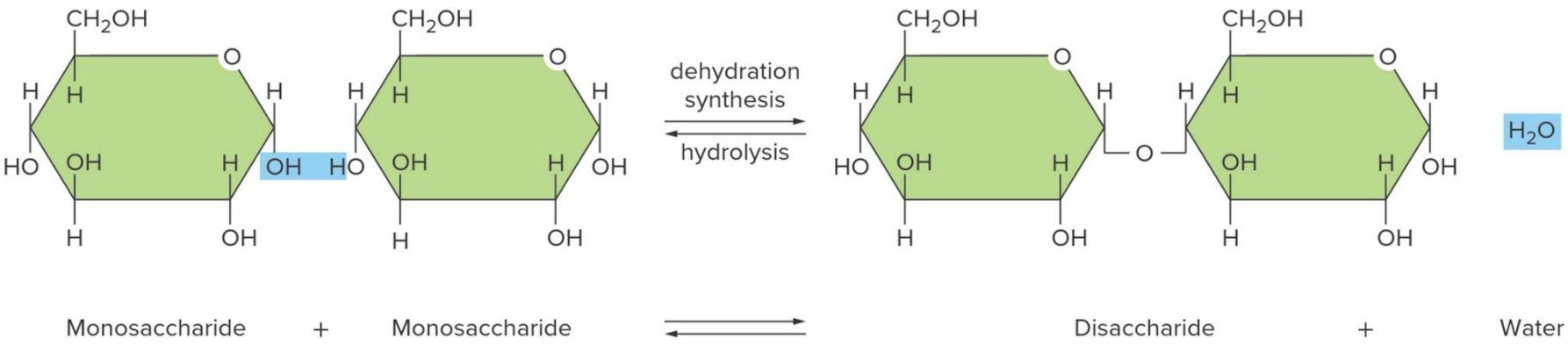
Polysaccharides, lipids, proteins, and nucleic acids are also constructed via **dehydration synthesis**:

- To synthesize a polysaccharide, many simple sugars (monosaccharides) bind together
- To form triglycerides (fats), glycerol and 3 fatty acids bind together
- Two bound amino acids form a *dipeptide*, while many join to form a *polypeptide*; the bond between two amino acids in a protein is called a *peptide bond*
- Nucleotides are joined together to synthesize nucleic acids

© McGraw Hill

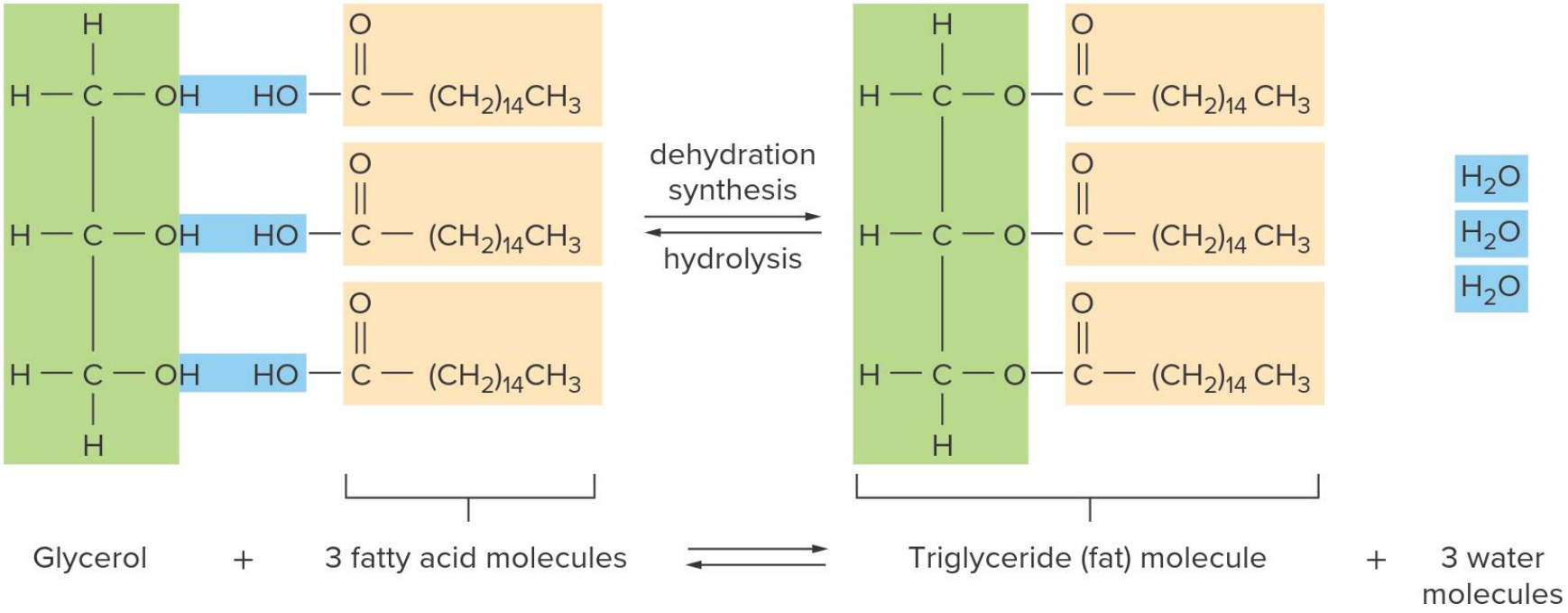
Dehydration Synthesis:
2 Monosaccharides Bind to Form a Disaccharide

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



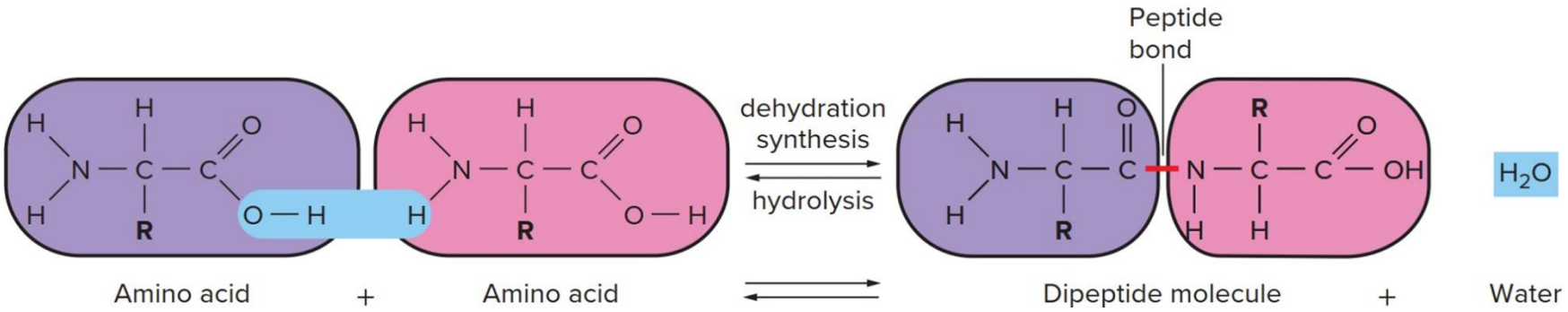
Dehydration Synthesis:
Glycerol + 3 Fatty Acids Form a Triglyceride

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Dehydration Synthesis:
2 Amino Acids Bind to Form a Dipeptide

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Catabolism

Catabolism breaks apart larger molecules into smaller ones (their building blocks)

These reactions occur by **hydrolysis**, a process by which a molecule of water is split, and its parts are inserted into a larger molecule to break its chemical bonds

Hydrolysis is responsible for digestion of dietary nutrients: carbohydrates, lipids, and proteins

General example: $\mathrm{A—O—B} + \mathrm{H_2O} \rightarrow \mathrm{A—OH} + \mathrm{H—OB}$

(A and B represent parts of a larger molecule to be split by hydrolysis)

Example: Sucrose (a disaccharide) + H_2O → Glucose + Fructose (which are monosaccharides)

Note: The reactions shown under anabolism are reversible; these reactions, when proceeding to the left, represent catabolic reactions

© McGraw Hill

4.3: Control of Metabolic Reactions

Enzyme action:

- **Enzymes** control the rates of all the metabolic reactions of the cell
- This is necessary because the temperature in cells is too low for the reactions to run fast enough to support life processes
- Enzymes are complex proteins that function to lower the **activation energy** of a reaction, so it may begin and proceed more rapidly; enzymes are therefore classified as **catalysts**
- Enzymes work in small quantities, and are not used up in the chemical reactions they catalyze, so they are recycled and re-used by the cell

© McGraw Hill

Enzyme Action

Each enzyme is **specific**, acting on only one kind of molecule, called the **substrate**

Enzymes recognize their substrates by their complementary shapes; the 3-dimensional structure of an enzyme that gives it specificity is called its **conformation**

Active sites on the enzyme combine with a special portion of the substrate, creating an **enzyme-substrate complex**

The binding of an enzyme and its substrate changes the shape of the substrate, so that the activation energy is lowered, and a reaction occurs

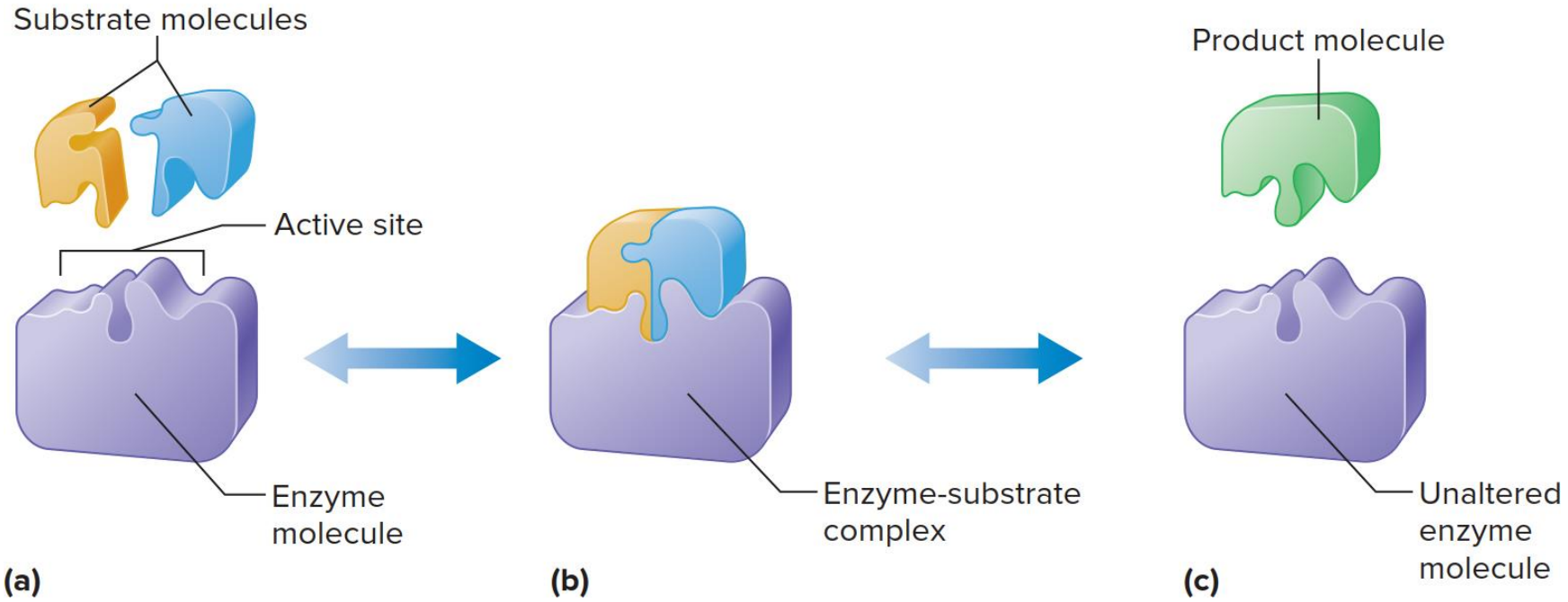
The speed of enzymatic reactions depends on the number of enzyme and substrate molecules available

At the end of the reaction, the enzyme is released, and can be used over by the cell

© McGraw Hill

An Enzyme-Catalyzed Reaction

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Enzymes and Metabolic Pathways

Different enzymes control each chemical reaction in the sequences of cellular metabolism

The enzymes controlling either an anabolic or catabolic sequence of reactions must act in a specific order

A sequence of enzyme-controlled reactions, both for synthesis and breakdown, is called a **metabolic pathway**

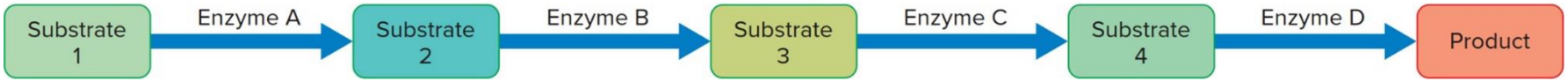
The rate of a metabolic pathway is determined by a **regulatory enzyme** responsible for one of its steps, by limiting the number of enzyme molecules available

A **rate-limiting enzyme** is a regulatory enzyme that controls the whole metabolic pathway; usually it is the first enzyme in the series of reactions

© McGraw Hill

An Enzyme-Controlled Metabolic Pathway

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Factors That Alter Enzymes

Some enzymes only become active when they combine with a nonprotein component called a **cofactor**

Cofactors may be ions of an element

Small organic cofactors are called **coenzymes;** these are often vitamins or derived from a vitamin

Enzymes (proteins) can be **denatured** by heat, pH extremes, chemicals, electricity, radiation, some poisons, and by other causes that render them nonfunctional

Enzyme denaturation, like that of other proteins, is irreversible

© McGraw Hill

4.4: Energy for Metabolic Reactions

Energy is the capacity change something or to do work

Common types of energy include heat, light, sound, electrical energy, mechanical energy, and chemical energy

Most metabolic reactions use **chemical energy**

© McGraw Hill

Release of Chemical Energy

Chemical energy is held in the **chemical bonds** of molecules, and is released when the bonds break

Release of chemical energy in the cell often occurs through the **oxidation** of glucose, in a process called **cellular respiration**

Cellular respiration reactions release chemical bond energy when nutrient molecules are broken down

This energy cannot be used directly, so it is stored in a molecule called ATP

About 40% of this energy is captured, and transferred to high-energy electrons that help to synthesize **ATP (adenosine triphosphate)**

The other 60% is released as heat, which is used to maintain the body temperature

© McGraw Hill

Adenosine Triphosphate (ATP)

ATP molecules contain three phosphates in a chain A cell uses ATP for many functions, including active transport and synthesis of various compounds

The **end (terminal) phosphate bond** of ATP, and the second phosphate bond, are called **high-energy bonds,** since they both store a lot of energy

Energy is stored while converting ADP (adenosine diphosphate) to ATP; when energy is released, ATP releases its terminal phosphate, and becomes ADP

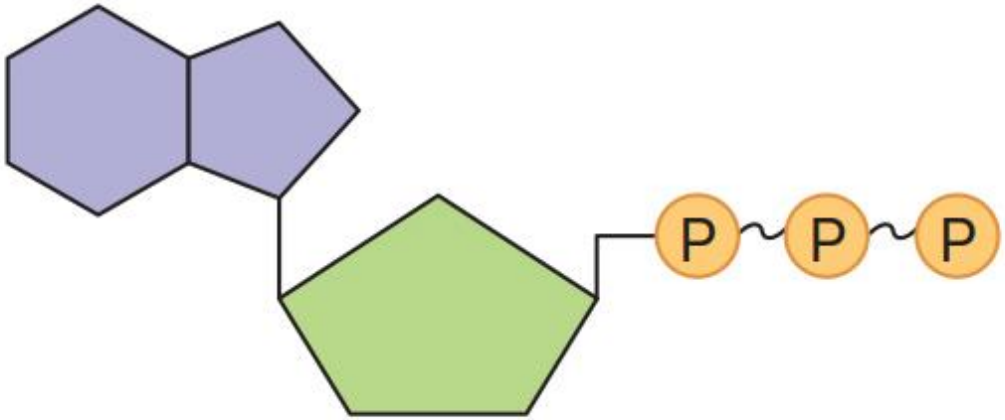
ADP can be converted back into ATP

ATP and ADP are interconverted between cellular respiration (which releases energy) and reactions in the cell (which utilize the energy)

© McGraw Hill

ATP Structure & High-Energy Phosphate Bonds

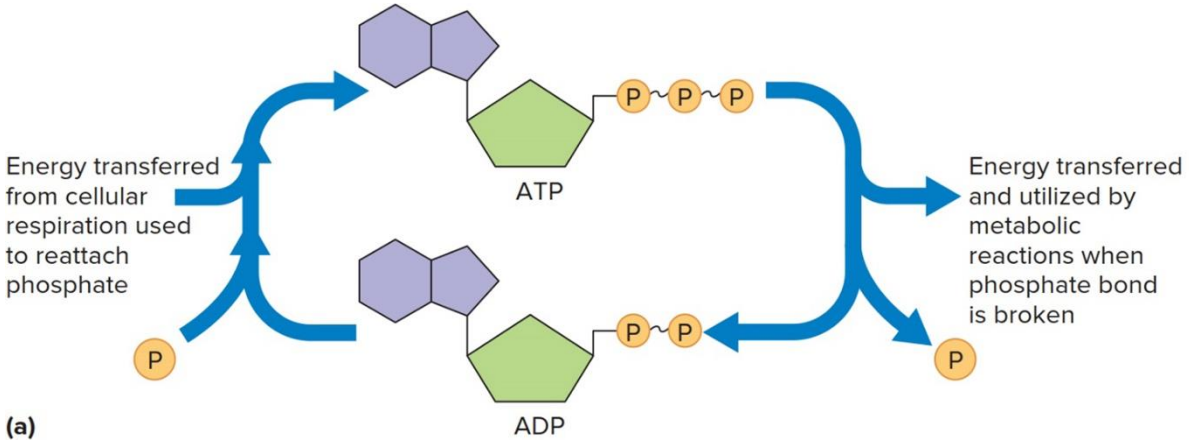
Copyright © McGraw-Hill Education. Permission required for reproduction or display.

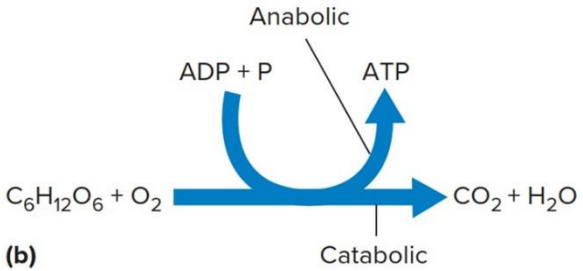


ATP

The Generation and Breakdown of ATP

Copyright © McGraw-Hill Education. Permission required for reproduction or display.





Cellular Respiration

Cellular respiration consists of three series of reactions, in which glucose is catabolized to carbon dioxide, water, and energy

The reaction series consists of **glycolysis**, the **citric acid cycle**, and the **electron transport chain**

Glycolysis and the citric acid cycle are stepwise **pathways**, while the citric acid cycle is a **cycle**

In a cycle, the product eventually re-forms the original substrate

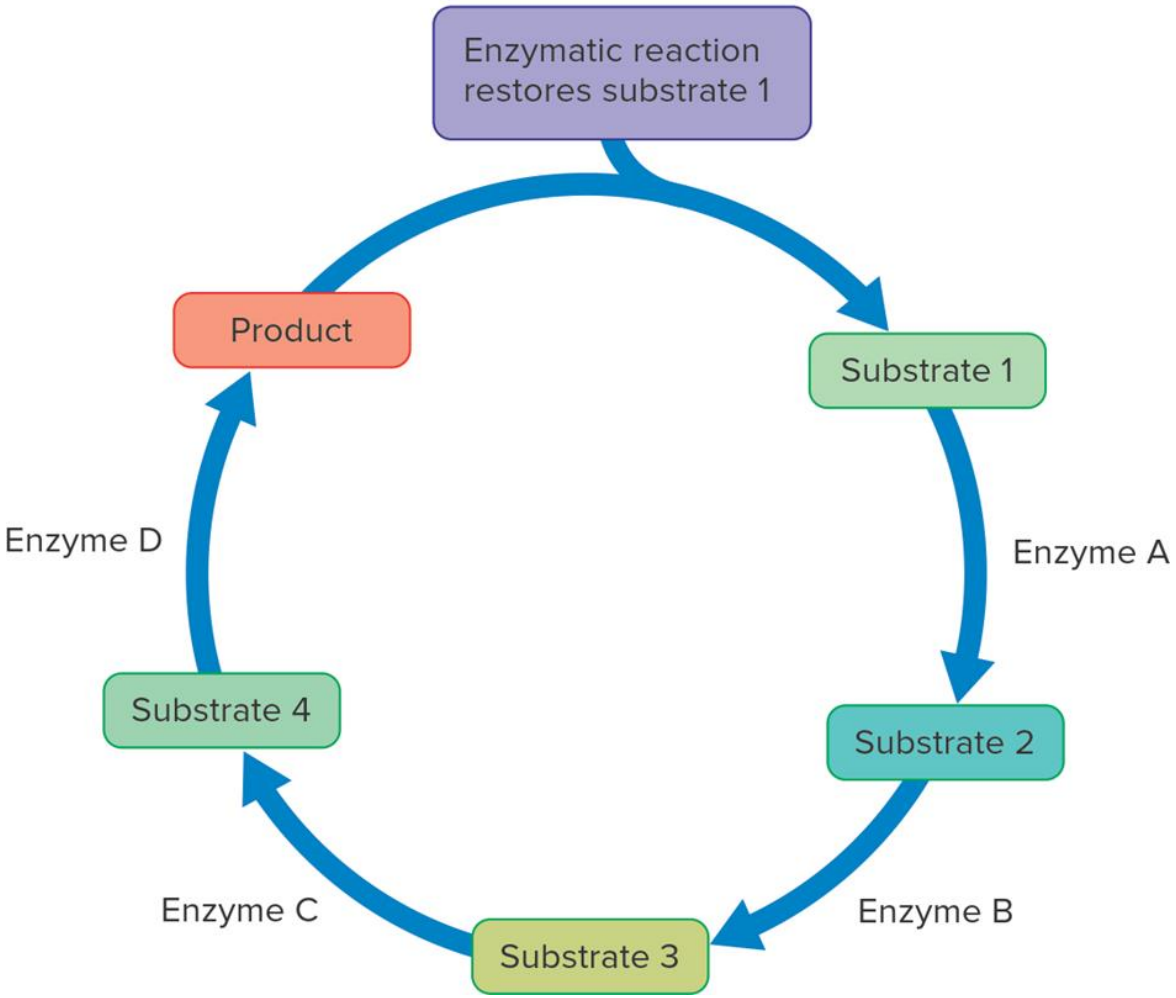
For the 3 reaction series, the reactants are glucose and O_2, and the final products are CO_2, water and energy:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

© McGraw Hill

A General View of a Metabolic Cycle

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Glycolysis

Glycolysis:

- The first reaction series of cellular respiration
- Involves the splitting of a 6-C **glucose** molecule into 2 3-C molecules of **pyruvic acid**
- Glycolysis occurs in the cytosol, and does not require oxygen (is **anaerobic**)
- Energy from ATP is used to start the process, but there is a net gain of ATP as a result
- Products of glycolysis are 2 pyruvic acid molecules, 2 ATP, and high-energy electrons
- After the synthesis of pyruvic acid, there are 2 possibilities:
  - If O_2 is not present, the pyruvic acid is converted into **lactic acid**
  - If O_2 is present, the pyruvic acid enters the **aerobic respiration pathways** in the mitochondria

© McGraw Hill

Aerobic Respiration

In the presence of O_2, **pyruvic acid** generated in glycolysis will enter the mitochondria, and start the aerobic respiration pathways (the **citric acid cycle**, followed by the **electron transport chain**)

Pyruvic acid will lose a carbon atom, and join with a coenzyme to form **acetyl coenzyme A (acetyl Co-A)**, which can enter the citric acid cycle

The **citric acid cycle** generates carbon dioxide, 2 ATP, and high-energy electrons

The **electron transport chain** takes the high-energy electrons from the other processes, and generates ~28 ATP from each glucose molecule that enters the pathways:

- The electron transport chain is also called oxidative phosphorylation, since it adds a phosphate to ADP to form ATP
- Oxygen is the last electron acceptor, and along with hydrogen, forms HO_2

Proteins and fats can also be broken down by aerobic respiration

© McGraw Hill

The Pathways of Cellular Respiration of Glucose

Glycolysis

1) The 6-carbon sugar glucose is broken down in the cytosol into two 3-carbon pyruvic acid molecules with a net gain of 2 ATP and the release of high-energy electrons.

Citric Acid Cycle

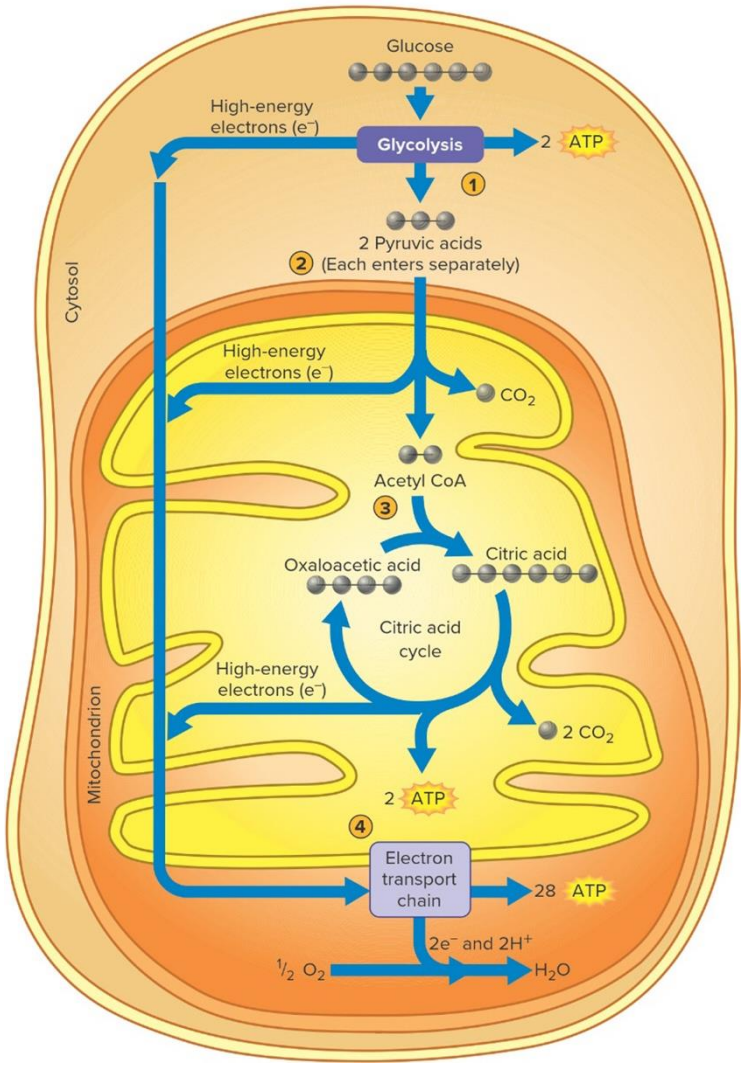
2) The 3-carbon pyruvic acids generated by glycolysis enter the mitochondria separately. Each loses a carbon (generating CO_2) and is combined with a coenzyme to form a 2-carbon acetyl coenzyme A (acetyl CoA). More high-energy electrons are released.

3) Each acetyl CoA combines with a 4-carbon oxaloacetic acid to form the 6-carbon citric acid, for which the cycle is named. For each citric acid, a series of reactions removes 2 carbons (generating 2 CO_2's), synthesizes 1 ATP, and releases more high-energy electrons. The figure shows 2 ATP resulting directly from 2 turns of the cycle per glucose molecule that enters glycolysis.

Electron Transport Chain

4) The high-energy electrons still contain most of the chemical energy of the original glucose molecule. Special carrier molecules bring the high-energy electrons to a series of enzymes that transfer much of the remaining energy to more ATP molecules. The electrons eventually combine with hydrogen ions and an oxygen atom to form water. The function of oxygen as the final electron acceptor in this last step is why the overall process is called aerobic respiration.

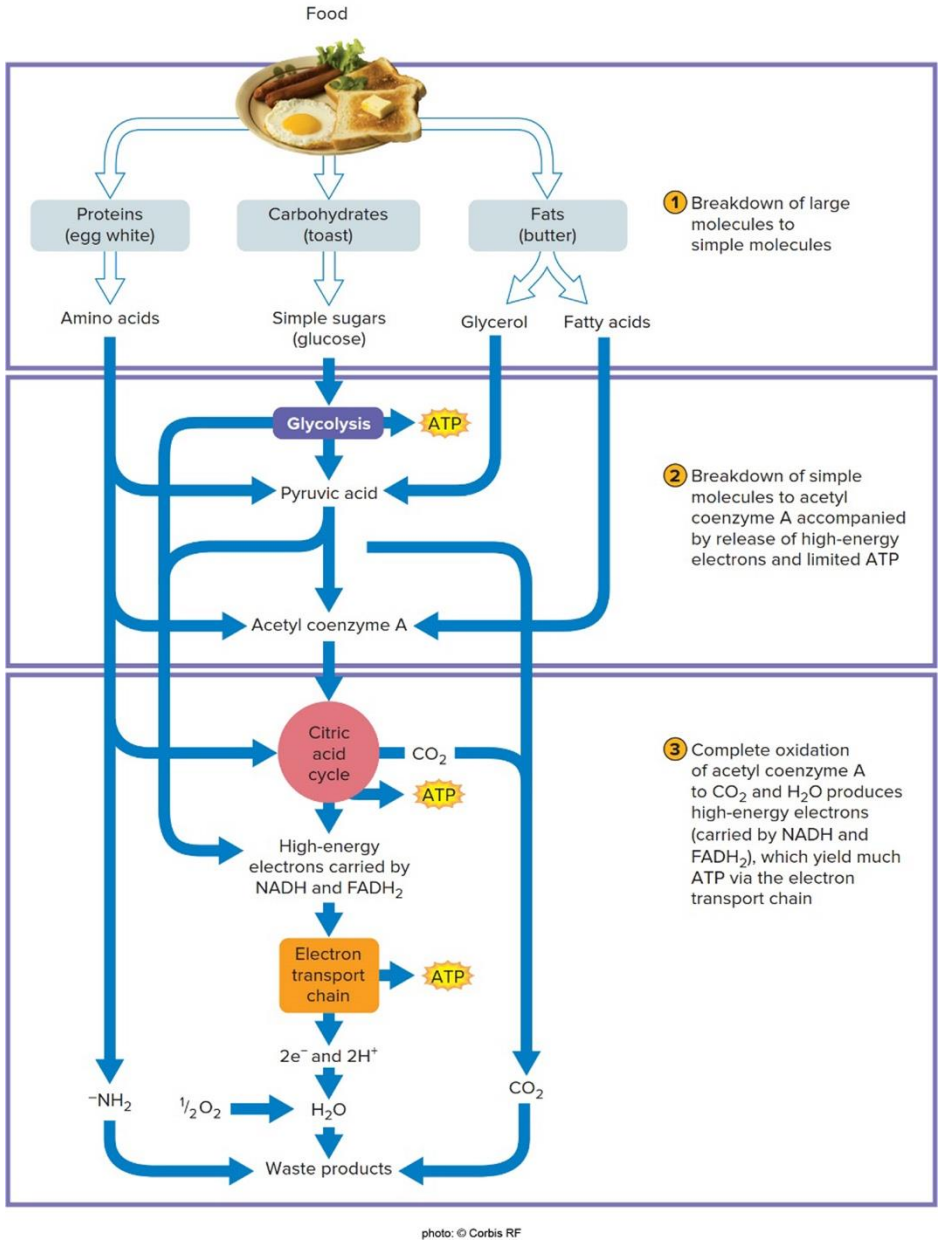
Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

Catabolism of Proteins, Carbohydrates, & Fats

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

4.5: DNA (Deoxyribonucleic Acid)

Deoxyribonucleic acid (DNA):

Contains the genetic code, the instructions needed for the synthesis of each protein (including enzymes) required by the cell

Genetic Information:

- A **gene** is a portion of a DNA molecule that contains the genetic information for making a single protein
- The complete set of genetic instructions for an organism is the **genome**
- The portion of the genome that encodes proteins (only about 1.5%) is the **exome**
- The rest of the genome regulates the activation of genes for protein synthesis

© McGraw Hill

DNA Molecules

DNA molecules consist of building blocks called **nucleotides**

The nucleotides of DNA form 2 **sugar-phosphate backbones,** with bases extending into the interior of the DNA molecule, which gives DNA a twisted ladder-like appearance

The **bases** found in DNA nucleotides are adenine (A), guanine (G), cytosine (C), and thymine (T)

The bases are joined to each other by weak hydrogen bonds

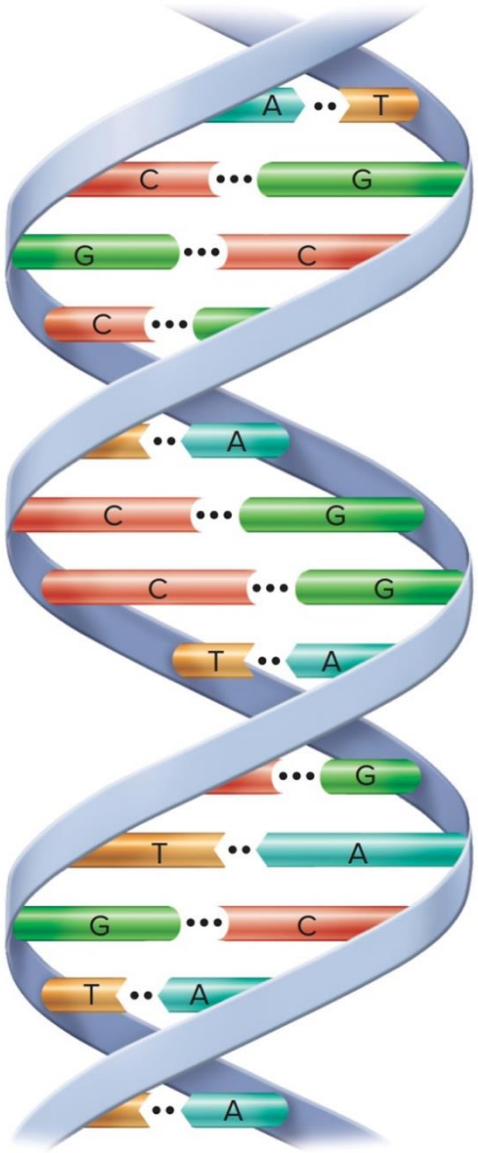
The nucleotides of one DNA strand exhibit **complementary base pairing** with those in the other strand (adenine pairs only with thymine; cytosine only with guanine)

The DNA molecule twists to form a **double helix,** and may be millions of base pairs long

© McGraw Hill

DNA Structure

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Access the text alternative for slide images.

DNA Replication 1

Each new cell must be provided with an exact replica of the parent cell's DNA

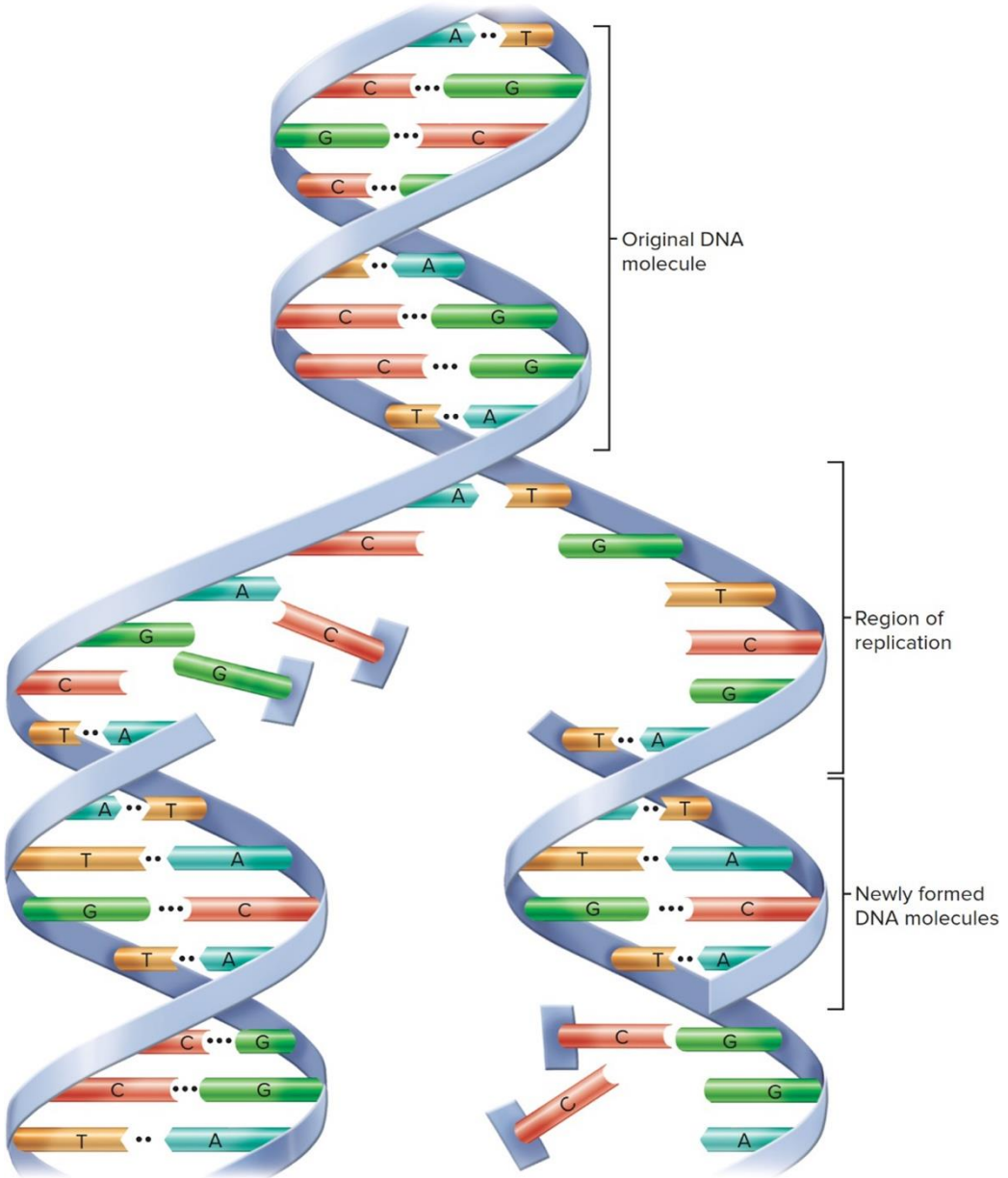
DNA replication (copying) occurs during **interphase:**

- The DNA double helix separates by breaking the hydrogen bonds between the base pairs
- Double helix unwinds and strands come apart
- **DNA polymerase** brings new nucleotides to each strand, which form complementary pairs with the original strands
- Other enzymes join the sugar-phosphate backbones together
- Each new DNA molecule consists of one parental strand and one newly-synthesized strand

© McGraw Hill

DNA Replication 2

Copyright © McGraw-Hill Education. Permission required for reproduction or display.



4.6: Protein Synthesis

DNA supplies genetic instructions for making proteins

The **genetic code** is the sequence of base pairs in a gene that specifies the order of amino acids to make a particular protein

An amino acid is represented by a **specific sequence of 3 nucleotides** on DNA

In the genetic code, nucleotide sequences also represent “start” and “stop” messages for each gene

The process of protein synthesis requires two sequential steps: **transcription** and **translation**

© McGraw Hill

Transcription 1

DNA molecules cannot leave the nucleus, but protein synthesis occurs in the cytoplasm

Therefore, the genetic information is copied onto a molecule of RNA, which is shorter than DNA and can leave the nucleus

RNA molecules differ from DNA in the following ways: they are single-stranded, contain ribose rather than deoxyribose, and contain uracil instead of thymine

The synthesis of **messenger RNA (mRNA)** molecules in the nucleus, in a sequence complementary to the DNA template strand, is called **transcription**

© McGraw Hill

Transcription 2

The enzyme **RNA polymerase** directs the synthesis of mRNA, according to the rules of complementary base pairing

RNA polymerase also recognizes the beginning and end of a particular gene, and which DNA strand is the proper one to copy

When the enzyme reaches the end of the gene, it releases the new mRNA strand; this completes the process of transcription

© McGraw Hill

A Comparison of DNA and RNA Molecules

TABLE 4.1 A Comparison of DNA and RNA Molecules

	DNA	RNA
Main location	Part of chromosomes, in nucleus	Cytoplasm
5-carbon sugar	Deoxyribose	Ribose
Basic molecular structure	Double-stranded	Single-stranded
Nitrogenous bases included	Adenine, thymine, cytosine, guanine	Adenine, uracil, cytosine, guanine
Major functions	Replicates prior to cell division; contains information for protein synthesis	mRNA carries transcribed DNA information to cytoplasm and acts as template for synthesis of protein molecules; tRNA carries amino acids to mRNA

© McGraw Hill

Complementary Base Pairs

TABLE 4.2 Complementary Base Pairs

Complementary strands of a DNA molecule	Complementary strands of a DNA molecule	Transcribed strand of DNA	Complementary strand of mRNA
A	T	A	U
T	A	T	A
C	G	C	G
G	C	G	C

© McGraw Hill

Translation 1

Each amino acid corresponds to a three-base sequence of DNA nucleotides; in the complementary mRNA, this sequence is called a **codon**

One codon represents a “start” message (at the beginning of a gene), and three represent “stop” messages (to signal the end of a gene)

mRNA moves out of the nucleus and associates with a **ribosome** in the cytoplasm, where the protein will be constructed in a process called **translation**

In the cytoplasm, another type of RNA, **transfer RNA (tRNA)**, has a three-base sequence of nucleotides called the **anticodon**, which is complementary to nucleotides of the messenger RNA codon

© McGraw Hill

Translation 2

The ribosome holds the mRNA in position, while the tRNA carries in the correct amino acid in sequence, with anticodons matching up to codons

Since there are 20 different types of amino acids, there are different types of tRNA for each amino acid

The ribosome contains enzymes needed to join the amino acids together by dehydration synthesis

As the amino acids are joined to each other, the new protein molecule folds into its unique shape, or **conformation**

© McGraw Hill

Codons (mRNA Three-Base Sequences)

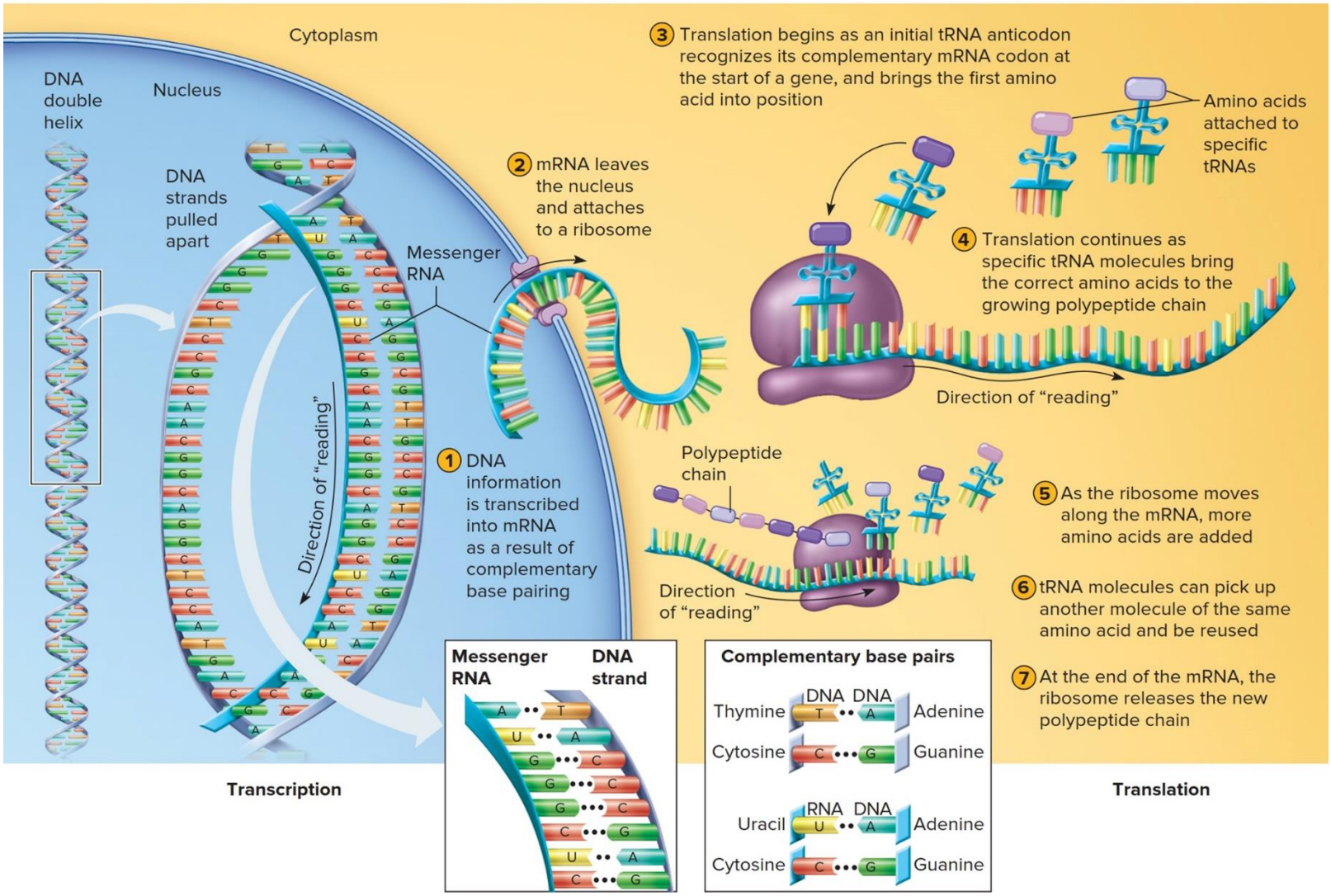
TABLE 4.3 Codons (mRNA Three-Base Sequences)

	SECOND LETTER U	SECOND LETTER C	SECOND LETTER A	SECOND LETTER G	
FIRST LETTER U	UUU: phenylalanine (phe)	UCU: serine (ser)	UAU: tyrosine (tyr)	UGU: cysteine (cys)	**THIRD LETTER** U
FIRST LETTER U	UUC: phenylalanine (phe)	UCC: serine (ser)	UAC: tyrosine (tyr)	UGC: cysteine (cys)	**THIRD LETTER** C
FIRST LETTER U	UUA: leucine (leu)	UCA: serine (ser)	UAA: STOP	UGA: STOP	**THIRD LETTER** A
FIRST LETTER U	UUG: leucine (leu)	UCG: serine (ser)	UAG: STOP	UGG: tryptophan (trp)	**THIRD LETTER** G
FIRST LETTER C	CUU: leucine (leu)	CCU: proline (pro)	CAU: histidine (his)	CGU: arginine (arg)	**THIRD LETTER** U
FIRST LETTER C	CUC: leucine (leu)	CCC: proline (pro)	CAC: histidine (his)	CGC: arginine (arg)	**THIRD LETTER** C
FIRST LETTER C	CUA: leucine (leu)	CCA: proline (pro)	CAA: glutamine (gln)	CGA: arginine (arg)	**THIRD LETTER** A
FIRST LETTER C	CUG: leucine (leu)	CCG: proline (pro)	CAG: glutamine (gln)	CGG: arginine (arg)	**THIRD LETTER** G
FIRST LETTER A	AUU: isoleucine (ile)	ACU: threonine (thr)	AAU: asparagine (asn)	AGU: serine (ser)	**THIRD LETTER** U
FIRST LETTER A	AUC: isoleucine (ile)	ACC: threonine (thr)	AAC: asparagine (asn)	AGC: serine (ser)	**THIRD LETTER** C
FIRST LETTER A	AUA: isoleucine (ile)	ACA: threonine (thr)	AAA: lysine (lys)	AGA: arginine (arg)	**THIRD LETTER** A
FIRST LETTER A	AUG: START methionine (met)	ACG: threonine (thr)	AAG: lysine (lys)	AGG: arginine (arg)	**THIRD LETTER** G
FIRST LETTER G	GUU: valine (val)	GCU: alanine (ala)	GAU: aspartic acid (asp)	GGU: glycine (gly)	**THIRD LETTER** U
FIRST LETTER G	GUC: valine (val)	GCC: alanine (ala)	GAC: aspartic acid (asp)	GGC: glycine (gly)	**THIRD LETTER** C
FIRST LETTER G	GUA: valine (val)	GCA: alanine (ala)	GAA: glutamic acid (glu)	GGA: glycine (gly)	**THIRD LETTER** A
FIRST LETTER G	GUG: valine (val)	GCG: alanine (ala)	GAG: glutamic acid (glu)	GGG: glycine (gly)	**THIRD LETTER** G

© McGraw Hill

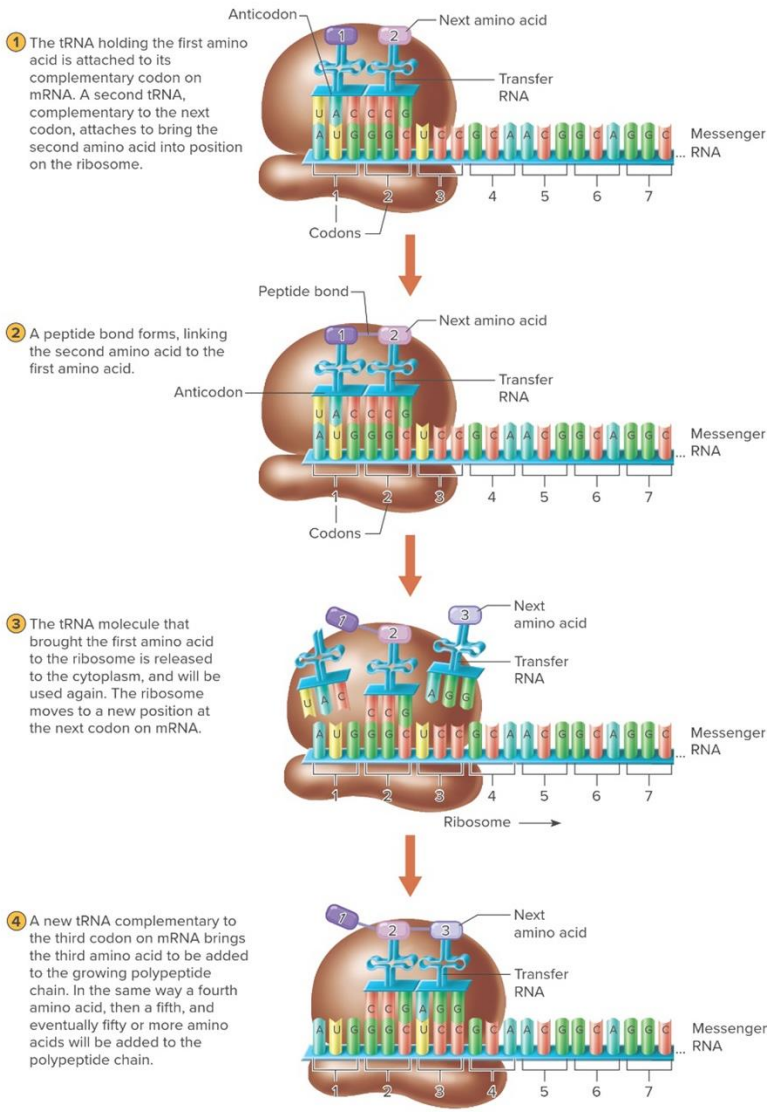
Protein Synthesis

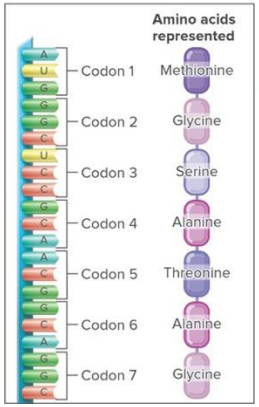
Copyright © McGraw-Hill Education. Permission required for reproduction or display.



Protein Synthesis on the Ribosomes

Copyright © McGraw-Hill Education. Permission required for reproduction or display.





Access the text alternative for slide images.

Translation 3

Correct protein folding is required for good health, and the functioning of the protein

Misfolded proteins are either refolded or destroyed by spool-shaped structures called **proteasomes**

A gene that has been transcribed and translated into a protein is said to be **expressed**

Gene expression is the basis for cell differentiation

© McGraw Hill



Because learning changes everything.®

www.mheducation.com

© 2021 McGraw Hill. All rights reserved. Authorized only for instructor use in the classroom.
No reproduction or further distribution permitted without the prior written consent of McGraw Hill.