3 Life and Chemistry: Large Molecules

OVERVIEW

Chapter 3 presents the major concepts of organic chemistry as they apply to the study of biology. The chapter describes the formation and functions of macromolecules. The four types of macromolecules, each having unique monomers and properties, are proteins, carbohydrates, nucleic acids, and lipids. Macromolecules interact by bonding to one another to form even more complex molecules.

WHAT'S NEW

In the Seventh Edition, Chapter 3 opens and ends by continuing the exploration of the origins of life that was begun in Chapter 2 and will conclude in Chapter 4. Portions of this material previously were located in Chapter 25. The section on proteins omits a paragraph on prosthetic groups and adds new information on the correlation of misfolded brain proteins and Alzheimer's disease. The section on lipids has been moved before the section on nucleic acids. In the latter section, a new subsection describes how "RNA may have been the first biological catalyst."

KEY CONCEPTS

1. Macromolecules are constructed by the formation of covalent bonds between smaller molecules called monomers.
2. Macromolecules have specific three-dimensional shapes and functional groups that determine their biological functioning and their interactions with other macromolecules.
3. Amino acids are the monomers of proteins and covalently bond by peptide linkages. Amino acids have varying properties based on their side chains.
4. The polypeptide chains of proteins are folded into specific three-dimensional shapes. Four levels of structure are possible: primary, secondary, tertiary, and quaternary.
5. The functions of proteins include support, protection, catalysis, transport, defense, regulation, and movement.
6. Monosaccharides are the monomers of carbohydrates.
7. Cellulose, starch, and glycogen are three important carbohydrate polymers.
8. The functions of carbohydrates include support and energy storage.
9. Nucleic acids are polymers made up of nucleotides.
10. In cells, DNA is the hereditary material. Both DNA and RNA play roles in the formation of proteins. Information flows from DNA to RNA to protein.
11. Fats and oils are composed of three fatty acids covalently bonded to a glycerol molecule by ester linkages.
12. Phospholipids have a hydrophobic hydrocarbon "tail" and a hydrophilic phosphate "head."
13. Lipids also include steroids, waxes, and some vitamins.
14. Lipids tend to be hydrophobic. Each type of lipid has a different function.

15. Both covalent and noncovalent linkages are found between the various classes of macromolecules.
16. Two examples of linkages between different classes of macromolecules are glycoproteins and the binding of cholesterol to protein.
17. Laboratory evidence supports the theory that RNA may have been the first biological catalyst.
18. Two theories of the origin of life are that life came from extraterrestrial sources and that life originated on Earth through chemical evolution.

CHAPTER OUTLINE

I. Theories of the Origin of Life
- A. Could life have come from outside Earth?
- B. Did life originate on Earth?

II. Macromolecules: Giant Polymers

III. Condensation and Hydrolysis Reactions

IV. Proteins: Polymers of Amino Acids
- A. Proteins are composed of amino acids
- B. Peptide linkages covalently bond amino acids together
- C. The primary structure of a protein is its amino acid sequence
- D. The secondary structure of a protein requires hydrogen bonding
- E. The tertiary structure of a protein is formed by bending and folding
- F. The quaternary structure of a protein consists of subunits
- G. The surfaces of proteins have specific shapes
- H. Protein shapes are sensitive to the environment
- I. Chaperonins help shape proteins

V. Carbohydrates: Sugars and Sugar Polymers
- A. Monosaccharides are simple sugars
- B. Glycosidic linkages bond monosaccharides together
- C. Polysaccharides serve as energy stores or structural materials
- D. Chemically modified carbohydrates contain other groups

VI. Lipids: Water-Insoluble Molecules
- A. Fats and oils store energy
- B. Phospholipids form the core of biological membranes
- C. Carotenoids and steroids
- D. Some lipids are vitamins
- E. Wax coatings repel water

VII. Nucleic Acids: Informational Macromolecules That Can Be Catalytic
- A. The nucleic acids have characteristic chemical properties
- B. The uniqueness of a nucleic acid resides in its nucleotide sequence
- C. DNA is a guide to evolutionary relationships
- D. RNA may have been the first biological catalyst
- E. Nucleotides have other important roles

VIII. All Life from Life

KEY TERMS

α helix
β pleated sheet
base
carbohydrates
carotenoids
cellulose
chaperonins
complementary base pairing
condensation reactions
denaturation
disulfide bridge
DNA
enzymes
glucose
glycogen
hydrolysis reaction
ligand
lipids
macromolecules
monomers
nucleic acids
nucleosides
nucleotides
phospholipids
polymers
primary structure
prosthetic groups
proteins
quaternary structure
R groups
ribozymes
RNA
saturated
secondary structure
starch
steroids
tertiary structure
triglycerides
unsaturated
vitamins

4 Cells: The Basic Units of Life

OVERVIEW

Chapter 4 examines the structures and functions of both prokaryotic and eukaryotic cells. The chapter opens with brief discussions of cell theory and the use of the microscope in studying cells. Next, Chapter 4 provides an overview of the types and structures of prokaryotic cells. The greater part of the chapter is devoted to describing the organelles and other parts of eukaryotic cells.

WHAT'S NEW

Throughout Chapter 4, the reader will find an increased use of bulleted items and also minor shifts in the location of material. The chapter opens by discussing Precambrian fossils, continuing the theme of life's origins begun in the previous chapters. Chapter 4 continues by considering whether cells could have originated from protobionts, information that previously was located in Chapter 25. The section on prokaryotic cells includes new material on the cytoskeleton. Under the section on eukaryotic cells, the discussion of cell parts opens with a new subsection and figure (Figure 4.8) on using both the microscope and cell fractionation to study organelles. The presentation of the Golgi apparatus now emphasizes the transport of vesicles over their fusion, and the discussion of lysosomes includes new information on lysosomal storage diseases, specifically Tay-Sachs disease.

KEY CONCEPTS

1. The cell is the basic unit of life. All cells come from pre-existing cells and have certain processes, types of molecules, and structures in common.
2. Cells may have originated from structures similar to the protobionts that can be produced in the laboratory.
3. To maintain adequate exchanges with its environment, a cell's surface area must be large compared with its volume.
4. Microscopes are needed to visualize cells. Because of their greater resolving power, electron microscopes allow observation of greater detail than can be seen with light microscopes.
5. Prokaryotic cell organization is characteristic of the domains Bacteria and Archaea. Prokaryotic cells lack internal compartments.
6. Prokaryotic cells each contain a nucleoid region and cytoplasm. Many also have cell walls, internal membranes, flagella, pili, and/or a cytoskeleton.
7. Eukaryotic cell organization is characteristic of cells in the domain Eukarya. Eukaryotic cells have many membrane-enclosed organelles, including a nucleus that contains DNA.
8. Organelles can be studied by microscopy or isolated by cell fractionation.
9. The nucleus is usually the largest organelle in a cell and contains most of the cell's DNA.
10. The rough endoplasmic reticulum has attached ribosomes that synthesize proteins. The smooth endoplasmic reticulum lacks ribosomes and is associated with the synthesis of lipids.

11. The Golgi apparatus packages proteins inside vesicles and directs their transport.
12. Lysosomes contain digestive enzymes.
13. Mitochondria are enclosed by an outer membrane and an inner membrane that folds inward to form cristae. Mitochondria contain the proteins needed for cellular respiration and the generation of ATP.
14. Chloroplasts are enclosed by two membranes and contain an internal system of thylakoids organized as grana. Chloroplasts carry out photosynthesis.
15. The endosymbiosis theory of the evolutionary origin of mitochondria and chloroplasts states that these organelles originated when larger prokaryotes engulfed, but did not digest, smaller prokaryotes. Mutual benefits permitted this symbiotic relationship to be maintained and to evolve into the eukaryotic organelles observed today.
16. Peroxisomes and glyoxysomes contain special enzymes and carry out specialized chemical reactions inside the cell.
17. Vacuoles are prominent in many plant cells and consist of a membrane-enclosed compartment that contains water and dissolved substances. By taking in water, vacuoles enlarge and provide the pressure needed to stretch the cell wall and provide structural support for the plant.
18. The cytoskeleton within the cytoplasm of eukaryotic cells provides shape, strength, and movement. It consists of three interacting types of protein fibers: microfilaments, which strengthen cellular structures and provide movement, intermediate filaments, which add strength to cell attachments in multicellular organisms, and microtubules, which are involved in the structure and function of cilia, flagella, and centrioles.
19. The cell wall of plants consists principally of cellulose. It is pierced by plasmodesmata that join the cytoplasm of adjacent cells.
20. In multicellular animals, the extracellular matrix consists of different kinds of proteins, including proteoglycan. In bone and cartilage, the protein collagen predominates.

CHAPTER OUTLINE

I. The Cell: The Basic Unit of Life
- A. Cells may have come from stable bubbles
- B. Cell size is limited by the surface area-to-volume ratio
- C. Microscopes are needed to visualize cells
- D. Cells are surrounded by a plasma membrane
- E. Cells show two organizational patterns

II. Prokaryotic Cells
- A. Prokaryotic cells share certain features
- B. Some prokaryotic cells have specialized features

III. Eukaryotic Cells
- A. Compartmentalization is the key to eukaryotic cell function
- B. Organelles can be studied by microscopy or isolated for chemical analysis

IV. Organelles that Process Information
- A. The nucleus contains most of the cell's DNA
- B. Ribosomes are the sites of protein synthesis

V. The Endomembrane System
- A. The endoplasmic reticulum is a complex factory
- B. The Golgi apparatus stores, modifies, and packages proteins
- C. Lysosomes contain digestive enzymes

VI. Organelles that Process Energy
- A. Mitochondria are energy transformers
- B. Plastids photosynthesize or store materials
- C. Endosymbiosis may explain the origin of mitochondria and chloroplasts

VII. Other Organelles
- A. Peroxisomes house specialized chemical reactions
- B. Vacuoles are filled with water and soluble substances

VIII. The Cytoskeleton
- A. Microfilaments function in support and movement
- B. Intermediate filaments are tough supporting elements
- C. Microtubules are long and hollow
- D. Microtubules power cilia and flagella
- E. Motor proteins move along microtubules

IX. Extracellular Structures
- A. The plant cell wall consists largely of cellulose
- B. Animal cells have elaborate extracellular matrices

KEY TERMS

actin
autophagy
basal body
cell fractionation
cell theory
cell wall
cellular respiration
centrioles
chlorophyll
chloroplast
chromatin
chromosomes
cilia
cytoplasm
cytoskeleton
cytosol
dynein
electron microscope
endomembrane system
endoplasmic reticulum (ER)
endosymbiosis
eukaryotic
extracellular matrix
flagella
glyoxysome
Golgi apparatus
grana
intermediate filaments
kinesin
light micoscope
lysosome
microfilaments
microtubules
mitochondrion
motor proteins

myosin
nuclear envelope
nuclear pores
nucleoid
nucleolus
nucleoplasm
nucleus
organelles
peroxisomes
phagocytosis
photosynthesis
plasma membrane
plastids
prokaryotic
protobionts
ribosomes
rough ER (RER)
smooth ER (SER)
stroma
surface area-to-volume ratio
symbiosis
thylakoids
tubulin
vacuole
vesicles

5 Cellular Membranes

OVERVIEW

Chapter 5 examines the structure and functions of cellular membranes. The chapter opens with a description of the composition, organization, and variability of membranes. Next is a discussion of the many ways that materials move across membranes and how membranes control these movements. Special attention is given to the importance of osmosis. The chapter closes with an introduction to other membrane functions.

WHAT'S NEW

Chapter 5 includes a number of minor organizational or wording changes and several additions to content. One content addition is the description of two ways that the movement of membrane proteins can be restricted. A second change is added detail in Figure 5.8, Osmosis Modifies the Shapes of Cells. The section on channel proteins contains new findings based on studies by Roderick MacKinnon. Finally, the section on carrier proteins includes additional detail in one figure (Figure 5.11) and a new paragraph contrasting passive and active transport.

KEY CONCEPTS

1. The fluid mosaic model of membrane structure describes a phospholipid bilayer in which membrane proteins can move about laterally within the membrane.
2. The two surfaces of a membrane may have different properties because of their different phospholipid composition, exposed domains of integral membrane proteins, and peripheral membrane proteins. Defined regions of a plasma membrane may have different membrane proteins.
3. Carbohydrates, attached to proteins or phospholipids, project from the external surface of the plasma membrane and function as recognition signals for interactions between cells.
4. In an organism or tissue, cells recognize and bind to each other by means of membrane proteins that protrude from the cell surface.
5. Some cells are connected by specialized cell junctions. The three types, tight junctions, desmosomes, and gap junctions, each have unique functions.
6. Substances can diffuse across a membrane by three processes: unaided diffusion through the phospholipid bilayer, diffusion through protein channels, or diffusion by means of a carrier protein (facilitated diffusion).
7. The rate of simple diffusion across a membrane is directly proportional to the concentration gradient across the membrane. An important factor in simple diffusion across a membrane is the lipid solubility of the solute.
8. In osmosis, water diffuses from regions of higher water concentration to regions of lower water concentration. Animal cells must remain isotonic to the environment to prevent destructive loss or gain of water. The cell walls of plants and some other organisms prevent the cells from bursting under hypotonic conditions. The turgor pressure that develops under these conditions

keeps plants upright and stretches the cell wall during plant cell growth.

9. Channel proteins and carrier proteins function in facilitated diffusion.
10. Active transport requires the use of energy to move substances across a membrane against a concentration gradient via active transport proteins.
11. Primary active transport uses energy from the hydrolysis of ATP to move ions into or out of cells against their concentration gradients, while secondary active transport couples the passive movement of one solute with its concentration gradient to the movement of another solute against its concentration gradient. Energy from ATP is used indirectly to establish the concentration gradient that results in the movement of the first solute.
12. Endocytosis transports macromolecules, large particles, and small cells into eukaryotic cells through engulfment by the plasma membrane.
13. Exocytosis secretes materials in vesicles from the cell by causing the vesicles to fuse with the plasma membrane.
14. Membranes function as sites for recognition and initial processing of extracellular signals, for energy transformations, and for organizing chemical reactions.
15. Membranes are dynamic, constantly forming, changing, and breaking down.

CHAPTER OUTLINE

I. Membrane Composition and Structure
- A. Lipids constitute the bulk of a membrane
- B. Membrane proteins are asymmetrically distributed
- C. Membrane carbohydrates are recognition sites

II. Cell Recognition and Adhesion
- A. Cell recognition and adhesion involve proteins at the cell surface
- B. Specialized cell junctions

III. Passive Processes of Membrane Transport
- A. The physical nature of diffusion
- B. Simple diffusion takes place through the membrane bilayer
- C. Osmosis is the diffusion of water across membranes
- D. Diffusion may be aided by channel proteins
- E. Carrier proteins aid diffusion by binding substances

IV. Active Transport
- A. Active transport is directional
- B. Primary and secondary active transport rely on different energy sources

V. Endocytosis and Exocytosis
- A. Macromolecules and particles enter the cell by endocytosis
- B. Receptor-mediated endocytosis is highly specific
- C. Exocytosis moves materials out of the cell

VI. Membranes Are Not Simply Barriers

VII. Membranes Are Dynamic

KEY TERMS

active transport
antiport
aquaporins
carrier proteins
cell junctions
channel proteins
coated pits
coated vesicle
desmosomes
diffusion
endocytosis
exocytosis
facilitated diffusion
fluid mosaic model
gap junctions
heterotypic
homotypic
hypertonic
hypotonic
integral membrane proteins
isotonic
osmosis
passive transport
peripheral membrane proteins
phagocytosis
pinocytosis
primary active transport
receptor-mediated endocytosis
secondary active transport
selective permeability
simple diffusion
symport
tight junctions
uniport

6 Energy, Enzymes, and Metabolism

OVERVIEW

Chapter 6 deals with energy and how cells use it. The chapter begins with a description of the first two laws of thermodynamics and their application to cellular processes. The role of ATP is highlighted, and the topic of enzymes is introduced. The second half of the chapter describes the structure and function of enzymes and their metabolic regulation.

WHAT'S NEW

In Chapter 6 the text has been condensed in a few areas and some minor details have been omitted. The section on the first law of thermodynamics omits two paragraphs contrasting closed and open systems. The section on the second law drops an example of entropy and the solar system and instead focuses on entropy and organisms. The description of chemical reactions removes references to spontaneous and nonspontaneous reactions. The description of ATP hydrolysis is condensed and rewritten. Finally, the discussion of allosteric enzymes has been reorganized and streamlined for the Seventh Edition.

KEY CONCEPTS

1. Energy is the capacity to do work. Energy occurs in two forms: potential and kinetic.
2. The first law of thermodynamics states that energy cannot be created or destroyed. The second law of thermodynamics states that, when energy is converted from one form to another, some of that energy becomes unavailable to do work.
3. Changes in free energy, total energy, temperature, and entropy are related by the equation $\Delta G = \Delta H - T\Delta S$.
4. Exergonic reactions have a negative ΔG, and endergonic reactions have a positive ΔG.
5. The change in free energy of a reaction determines its point of chemical equilibrium, at which the forward and reverse reactions proceed at the same rate.
6. ATP (adenosine triphosphate) serves as an energy currency in cells. The ATP cycle couples exergonic and endergonic reactions.
7. The rate of a chemical reaction is independent of G but is determined by the size of the activation energy barrier. Catalysts speed reactions by lowering the activation energy barrier.
8. Enzymes are biological catalysts, proteins that are highly specific for their substrates.
9. An enzyme's active site determines its specificity. At the active site, a molecule of substrate can be oriented correctly, chemically modified, or strained. Also, upon binding to a substrate, some enzymes change shape, facilitating the reaction.
10. Substrate concentration affects the rate of an enzyme-catalyzed reaction.

11. Some enzymes require cofactors, coenzymes, or prosthetic groups in order to facilitate a reaction.
12. Metabolism is organized into pathways, in which the product of one reaction is a reactant for the next reaction. Each reaction is catalyzed by an enzyme.
13. Enzyme activity is subject to regulation from irreversible and reversible inhibitors.
14. Unlike enzymes with single subunits, the activity of allosteric enzymes results from the activity of both positive and negative regulators. A plot of reaction rate versus substrate concentration for allosteric enzymes results in a sigmoid curve.
15. The end product of a metabolic pathway may inhibit the allosteric enzyme that catalyzes the commitment step of the pathway.
16. Enzymes are sensitive to their environment. Both pH and temperature affect enzyme activity.

CHAPTER OUTLINE

I. Energy and Energy Conversions
- A. Energy changes are related to changes in matter
- B. The first law: Energy is neither created nor destroyed
- C. The second law: Not all energy can be used, and disorder tends to increase
- D. Chemical reactions release or take up energy
- E. Chemical equilibrium and free energy are related

II. ATP: Transferring Energy in Cells
- A. ATP hydrolysis releases energy
- B. ATP couples exergonic and endergonic reactions

III. Enzymes: Biological Catalysts
- A. For a reaction to proceed, an energy barrier must be overcome
- B. Enzymes bind specific reactant molecules
- C. Enzymes lower the energy barrier but do not affect equilibrium
- D. What are the chemical events at active sites of enzymes?

IV. Molecular Structure Determines Enzyme Function
- A. The active site is specific to the substrate
- B. An enzyme changes shape when it binds a substrate
- C. Some enzymes require other molecules in order to operate
- D. Substrate concentration affects reaction rate

V. Metabolism and the Regulation of Enzymes
- A. Metabolism is organized into pathways
- B. Enzyme activity is subject to regulation by inhibitors
- C. Allosteric enzymes control their activity by changing their shape
- D. Allosteric effects regulate metabolism
- E. Enzymes are affected by their environment

KEY TERMS

activation energy
active site
adenosine diphosphate (ADP)
adenosine triphosphate (ATP)
allosteric regulator
allostery
anabolic reactions
catabolic reactions
catalysts
chemical equilibrium
coenzymes
cofactors
commitment step
competitive inhibitors
endergonic
end-product inhibition
energy
enthalpy
entropy
enzymes
enzyme–substrate complex
exergonic
feedback inhibition
first law of thermodynamics
free energy
induced fit
irreversible inhibitor
isozymes
kinetic energy
metabolism
noncompetitive inhibitors
pathways
potential energy
prosthetic groups
ribozymes
second law of thermodynamics
substrates

7 Cellular Pathways That Harvest Chemical Energy

OVERVIEW

Chapter 7 opens with a brief overview of the principles of metabolic pathways, then continues with a presentation of the role of glucose in providing energy and electrons to cells. The body of the chapter describes the events of both anaerobic and aerobic respiration. Chapter 7 closes with the integration and regulation of metabolic and energy pathways.

WHAT'S NEW

Chapter 7 contains a number of changes. The definition of fermentation has been moved from early in the chapter to the fermentation section later in the chapter. The section entitled "An Overview: Releasing Energy from Glucose" has been shortened, although the information is retained in the figures and later sections of the chapter. In the description of the energy-harvesting reactions of glycolysis, the details of G3P conversion are omitted in favor of emphasizing the reactions involving NADH. The portion of the chapter covering the respiratory chain has been rewritten and reorganized and includes new details of the process. The fermentation section adds more examples of organisms having various anaerobic or aerobic metabolic strategies. The new edition omits the former concluding section of the chapter, "Evolution has led to metabolic efficiency" in favor of a brief statement early in the chapter about evolution's role in metabolism. Finally, several of the figures have been partially or completely redrawn.

KEY CONCEPTS

1. The aerobic metabolism of glucose is expressed by the equation

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

   This reaction is accomplished in many separate steps so that the energy can be captured as ATP.
2. Redox reactions transfer large amounts of energy. Much of the energy liberated by the oxidation of the reducing agent is captured in the reduction of the oxidizing agent.
3. NAD is a key electron carrier in biological redox reactions. It exists in two forms, one oxidized (NAD^+) and the other reduced ($NADH + H^+$).
4. Glycolysis is a pathway of ten enzyme-catalyzed reactions located in the cytoplasm, in which glucose is split into 2 pyruvate molecules. Glycolysis provides starting materials for both cellular respiration and fermentation.
5. The pyruvate dehydrogenase complex catalyzes three reactions: (1) Pyruvate is oxidized to acetate, releasing one CO_2 molecule and considerable energy. (2) Some of this energy is captured when NAD^+ is reduced to $NADH + H^+$. (3) The remaining energy is captured when acetate is combined with coenzyme A, yielding energy-rich acetyl CoA.

6. The energy in acetyl CoA drives the reaction of acetate with oxaloacetate to produce citrate. The citric acid cycle is a series of reactions in which citrate is oxidized and oxaloacetate regenerated. It produces 2 CO_2, 1 $FADH_2$, 3 NADH, and 1 ATP for each acetyl CoA.
7. The respiratory chain oxidizes NADH + H^+ and $FADH_2$ from glycolysis, pyruvate oxidation, and the citric acid cycle, thereby regenerating NAD^+ and FAD. Oxygen (O_2) is the final acceptor of electrons and protons, forming water (H_2O).
8. The chemiosmotic mechanism couples proton transport to oxidative phosphorylation, yielding ATP.
9. Many organisms and some cells live without O_2, deriving all their energy from glycolysis and fermentation reactions and, generating end products such as lactic acid or ethanol.
10. For each molecule of glucose used, fermentation yields 2 molecules of ATP. In contrast, glycolysis operating with pyruvate oxidation, the citric acid cycle, and the respiratory chain yields up to 36 molecules of ATP per molecule of glucose.
11. Catabolic pathways result in products used in the respiratory pathways. Polysaccharides are broken down into glucose, which enters glycolysis. Glycerol from fats also enters glycolysis, and acetate from fatty acid degradation forms acetyl CoA to enter the citric acid cycle. Proteins enter glycolysis and the citric acid cycle via amino acids.
12. Anabolic pathways use intermediate components of respiratory metabolism to synthesize fats, amino acids, and other essential building blocks for cellular structure and function.
13. The rates of glycolysis and the citric acid cycle are increased or decreased by the actions of ATP, ADP, NAD^+, or NADH + H^+ on allosteric enzymes.

CHAPTER OUTLINE

I. Energy and Electrons from Glucose
- A. Cells trap free energy while metabolizing glucose
- B. Redox reactions transfer electrons and energy
- C. The coenzyme NAD is a key electron carrier in redox reactions

II. An Overview: Releasing Energy from Glucose

III. Glycolysis: From Glucose to Pyruvate
- A. The energy-investing reactions of glycolysis require ATP
- B. The energy-harvesting reactions of glycolysis yield NADH + H^+ and ATP

IV. Pyruvate Oxidation

V. The Citric Acid Cycle
- A. The citric acid cycle produces two CO_2 molecules and reduced carriers

VI. The Respiratory Chain: Electrons, Protons, and ATP Production
- A. The respiratory chain transports electrons and releases energy
- B. Proton diffusion is coupled to ATP synthesis

VII. Fermentation: ATP from Glucose, without O_2
- A. Some fermenting cells produce lactic acid and some produce alcohol

VIII. Contrasting Energy Yields

IX. Relationships between Metabolic Pathways
- A. Catabolism and anabolism involve interconversions using carbon skeletons
- B. Catabolism and anabolism are integrated

X. Regulating Energy Pathways

KEY TERMS

acetyl CoA
aerobic
alcoholic fermentation
allosteric control
anaerobic
ATP synthase
cellular respiration
chemiosmosis
citric acid cycle
coenzyme A
cytochrome *c*
electron transport chain
fermentation
flavin adenine dinucleotide (FAD)
gluconeogenesis
glucose
glycolysis
isocitrate dehydrogenase
kinase
lactic acid fermentation
NAD^+
NADH + H^+
nicotinamide adenine dinucleotide (NAD)
oxidation
oxidative phosphorylation
phosphofructokinase
proton-motive force
pyruvate
pyruvate oxidation
redox reaction
reduction
respiratory chain
substrate-level phosphorylation
ubiquinone

9 Chromosomes, the Cell Cycle, and Cell Division

OVERVIEW

After a brief description of cell division in prokaryotes, Chapter 9 focuses on eukaryotic cell division. The chapter covers the cell cycle and the principal molecules that control cell division, then gives detailed descriptions of mitosis and meiosis. Asexual and sexual reproduction are contrasted, and some of the consequences of meiotic errors are examined.

WHAT'S NEW

In Chapter 9, the section "Cyclins and other proteins signal events in the cell cycle" incorporates new information on the role of retinoblastoma protein while omitting a paragraph on cyclin-Cdk target molecules. There is an expanded explanation of phosphorylation and details about the various cyclins have been added to Figure 9.4. The description of the structure of eukaryotic chromosomes now includes the roles of cohesin and condensin proteins. Cohesin also is mentioned in the paragraph on metaphase, along with the protease that acts on it. The new Figure 9.9 illustrates this activity.

KEY CONCEPTS

1. Cell division consists of three steps: replication of the genetic material (DNA), partitioning of the two DNA molecules to separate portions of the cell, and division of the cytoplasm.
2. In prokaryotes, cellular DNA is a single molecule, or chromosome. Prokaryotes reproduce by cell fission.
3. In eukaryotes, nuclei divide either by mitosis or meiosis.
4. During most of the cell cycle, the cell is in interphase, which is divided into three subphases: S, G1, and G2. Some cells enter a resting phase called G0.
5. A cell can be stimulated to begin a division cycle by its internal cyclin-Cdk complexes and by external controls such as growth factors and hormones.
6. During interphase, the DNA in chromatin is wound around cores of histone proteins to form nucleosomes. DNA folds over and over again, packing itself within the nucleus. When mitotic chromosomes form, it folds even more.
7. Replicated chromosomes consist of two chromatids that are held together along their length by cohesin proteins. At mitosis, most of the cohesin is removed, except at the centromere region. Additionally, condensin proteins coat the chromatids and make them more compact.
8. Mitosis can be divided into several phases, called prophase, prometaphase, metaphase, anaphase, and telophase.
9. During prophase, the chromosomes condense and appear as paired chromatids. During prometaphase, the chromosomes move toward the middle of the spindle. In metaphase, they gather at the middle of the cell with their centromeres on the equatorial plate. At the end of metaphase, the centromeres holding together the chromatid pairs separate, and during anaphase each member of the pair, now called a daughter chromosome, migrates to its pole

along the microtubule track. During telophase, the chromosomes become less condensed. The nuclear envelopes and nucleoli re-form, thus producing two nuclei whose chromosomes are identical to each other and to those of the cell that began the cycle.

10. Nuclear division is usually followed by cytokinesis. Animal cell cytoplasm usually divides by a furrowing of the plasma membrane. In plant cells, cytokinesis is accomplished by vesicle fusion and the synthesis of new cell wall material.
11. Asexual reproduction produces a new organism that is genetically identical to the parent. Sexual reproduction forms a genetically unique organism.
12. Meiosis reduces the chromosome number from diploid to haploid and ensures that each haploid cell contains one member of each chromosome pair. It consists of two nuclear divisions.
13. During prophase I, homologous chromosomes pair up with each other, and material may be exchanged by crossing over between nonsister chromatids of two adjacent homologs. In metaphase I, the paired homologs gather at the equatorial plate. In anaphase I, entire chromosomes, each with two chromatids, migrate to the poles. By the end of meiosis I, there are two nuclei, each with the haploid number of chromosomes with two sister chromatids.
14. In meiosis II, the sister chromatids separate. No DNA replication precedes this division, which in other aspects is similar to mitosis. The result of meiosis is four cells, each with a haploid chromosome content.
15. Both crossing over during prophase I and the random selection of which homolog of a pair migrates to which pole during anaphase I ensure that the genetic composition of each haploid gamete is different from that of the parent and from that of the other gametes. The more chromosome pairs there are in a diploid cell, the greater the diversity of chromosome combinations generated by meiosis.
16. In nondisjunction, one member of a homologous pair of chromosomes fails to separate from the other during meiosis I, and both go to the same pole. This event leads to one gamete with an extra chromosome and another lacking that chromosome. Fertilization with a normal haploid gamete results in aneuploidy and genetic abnormalities that are invariably harmful or lethal to the organism.
17. Cells may die by necrosis or may self-destruct by apoptosis, a genetically programmed series of events that includes the detachment of the cell from its neighbors and the fragmentation of its nuclear DNA.

CHAPTER OUTLINE

I. Systems of Cell Reproduction
- A. Prokaryotes divide by fission
- B. Eukaryotic cells divide by mitosis or meiosis

II. Interphase and the Control of Cell Division
- A. Cyclins and other proteins signal events in the cell cycle
- B. Growth factors can stimulate cells to divide

III. Eukaryotic Chromosomes

IV. Mitosis: Distributing Exact Copies of Genetic Information
- A. The centrosomes determine the plane of cell division
- B. Chromatids become visible and the spindle forms during prophase
- C. Chromosome movements are highly organized
- D. Nuclei re-form during telophase

V. Cytokinesis: The Division of the Cytoplasm

VI. Reproduction: Asexual and Sexual
- A. Reproduction by mitosis results in genetic constancy
- B. Reproduction by meiosis results in genetic diversity
- C. The number, shapes, and sizes of the metaphase chromosomes constitute the karyotype

VII. Meiosis: A Pair of Nuclear Divisions
- A. The first meiotic division reduces the chromosome number
- B. The second meiotic division separates the chromatids
- C. Meiosis leads to genetic diversity

VIII. Meiotic Errors
- A. Aneuploidy can give rise to genetic abnormalities
- B. Polyploids can have difficulty in cell division

IX. Cell Death

KEY TERMS

anaphase
aneuploidy
apoptosis
asexual reproduction
cell cycle
centrioles
centromere
centrosome
chiasmata
chromatin
chromosome
cohesin
condensin
crossing over
cyclin
cyclin-dependent kinase (Cdk)
cytokinesis
daughter chromosome
diploid
equatorial plate
fertilization
fission
G0
G1
G2
gametes
growth factors

haploid
histones
homologous pair
independent assortment
interkinesis
interphase
karyotype
kinetochores
M phase
meiosis
meiosis I
meiosis II
metaphase
mitosis
monosomic
necrosis
nondisjunction
nucleosomes
polyploid
prometaphase
prophase
replication
S phase
segregation
sexual reproduction
sister chromatids
somatic cells
spindle
spores
synapsis
telophase
tetrad
translocation
trisomic
zygote

10 Genetics: Mendel and Beyond

OVERVIEW

Chapter 10 is an introduction to genetics, from Mendel to today. The chapter begins with a detailed discussion of Mendel's work and describes the experiments he used to define his two laws of inheritance. Then extensions of Mendelian analysis are discussed, including allelic interactions, epistasis, and linkage. The final portion of the chapter deals with chromosome structure and inheritance with special mention of the sex chromosomes. The last section describes cytoplasmic inheritance.

WHAT'S NEW

In Chapter 10 the section on incomplete dominance no longer includes paragraphs discussing the molecular basis or overall frequency. The presentation of gene linkage omits two figures, one showing male and female fruit flies and the other depicting the results of a hypothetical cross with absolute linkage. In addition, the section entitled "Polygenes mediate quantitative inheritance," which was accompanied by a figure showing the polygenic inheritance of human skin pigmentation, has been replaced with a new section called "Most complex phenotypes are determined by multiple genes and environment" and a new figure on quantitative variation.

KEY CONCEPTS

1. Before Mendel's time it was believed that during reproduction the units of inheritance blended and could never be separated.
2. In Mendel's monohybrid crosses, when the F_1 offspring were self-pollinated, the resulting F_2 generation showed a 3:1 phenotypic ratio, with the recessive phenotype present in one-fourth of the offspring. This reappearance of the recessive phenotype refuted the blending hypothesis.
3. Because some alleles are dominant and some are recessive, the same phenotype can result from different genotypes. Homozygous genotypes have two copies of the same allele; heterozygous genotypes have two different alleles. Heterozygous genotypes yield phenotypes that show the dominant trait.
4. On the basis of many crosses using different characters, Mendel proposed his first law: The units of inheritance (now known as genes) are particulate, there are two copies (alleles) of each gene in every parent, and during gamete formation the two alleles for a character segregate from each other.
5. Geneticists who followed Mendel showed that genes are carried on chromosomes and that alleles are segregated during meiosis I.
6. Using a test cross, Mendel was able to determine whether a plant showing the dominant phenotype was homozygous or heterozygous. The appearance of the recessive phenotype in half of the offspring of such a cross indicates that the parent is heterozygous.
7. From studies of the simultaneous inheritance of two characters, Mendel proposed his law of independent assortment: Alleles of different genes assort independently.

8. We can predict the results of hybrid crosses either by using a Punnett square or by calculating probabilities.
9. New alleles arise by mutation, and many genes have multiple alleles.
10. Dominance is usually not complete, since both alleles in a heterozygous organism may be expressed in the phenotype.
11. In epistasis, the products of different genes interact to produce a phenotype.
12. In some cases, the phenotype is the result of the additive effects of several genes (polygenes), and inheritance is quantitative.
13. Environmental variables such as temperature, nutrition, and light affect gene action.
14. Each chromosome carries many genes. Genes located on the same chromosome are said to be linked, and they are often inherited together. Linked genes can recombine by crossing over in prophase I of meiosis.
15. The distance between genes on a chromosome is proportional to the frequency of crossing over between them. Genetic maps are based on recombinant frequencies.
16. Sex chromosomes carry genes that determine whether male or female gametes are produced. The specific functions of X and Y chromosomes differ among species.
17. In fruit flies and mammals, the X chromosome carries many genes, but its homolog, the Y chromosome, has only a few. Males have only one allele for most X-linked genes, so rare alleles show up phenotypically more often in males than in females.
18. Cytoplasmic organelles such as plastids and mitochondria contain some heritable genes.
19. Cytoplasmic inheritance is generally by way of the egg (maternal), because male gametes contribute only their nucleus to the zygote at fertilization.

CHAPTER OUTLINE

I. The Foundations of Genetics
- A. Plant breeders showed that both parents contribute equally to inheritance
- B. Mendel brought new methods to experiments on inheritance

II. Mendel's Experiments and the Laws of Inheritance
- A. Mendel devised a careful research plan
- B. Mendel's experiment 1 examined a monohybrid cross
- C. Mendel's first law says that alleles segregate
- D. Mendel verified his hypothesis by performing a test cross
- E. Mendel's second law says that alleles of different genes assort independently
- F. Punnett squares or probability calculations: A choice of methods
- G. Mendel's laws can be observed in human pedigrees

III. Alleles and Their Interactions
- A. New alleles arise by mutation
- B. Many genes have multiple alleles
- C. Dominance is not always complete
- D. In codominance, both alleles are expressed
- E. Some alleles have multiple phenotypic effects

IV. Gene Interactions
- A. Some genes alter the effects of other genes
- B. Hybrid vigor results from new gene combinations and interactions
- C. The environment affects gene action
- D. Most complex phenotypes are determined by multiple genes and environment

V. Genes and Chromosomes
- A. Genes on the same chromosome are linked
- B. Genes can be exchanged between chromatids
- C. Geneticists can make maps of chromosomes

VI. Sex Determination and Sex-Linked Inheritance
- A. Sex is determined in different ways in different species
- B. The X and Y chromosomes have different functions
- C. Humans display many sex-linked characters

VII. Non-Nuclear Inheritance

KEY TERMS

alleles
autosomes
character
codominance
continuous
dihybrid cross
dominant
epistasis
expressivity
first filial generation (F_1)
gene
genetic maps
genotype
hemizygous
heritable
heterosis
heterozygous
homozygous
hybrid vigor
incomplete dominance
law of independent assortment
law of segregation
linked
locus (loci)
map units
monohybrid cross
mutations
parental generation (P)
particulate theory
pedigrees
penetrance
phenotype
pleiotropic
polymorphic
Punnett square
qualitative
quantitative
quantitative trait loci
recessive
reciprocal crosses
recombinant

recombinant frequencies
second filial generation (F2)
sex determination
sex-linked
test cross
trait
true-breeding
wild type

11 DNA and Its Role in Heredity

OVERVIEW

Chapter 11 examines DNA in detail. The chapter opens with a description of the classic experiments that showed that DNA is the genetic material. The chapter continues with a description of the experiments that determined the structure of DNA and how it is replicated. The importance of accurate replication is also discussed, as well as the mechanisms that repair DNA. Chapter 11 closes with an overview of some practical applications of understanding DNA replication.

WHAT'S NEW

The most significant change in Chapter 11 is a new section called "Telomeres are not fully replicated." The chapter also contains new findings on the variety of DNA polymerases in the section "Cells contain several different DNA polymerases." Several omissions since the last edition include a table listing the percentages of the nitrogen bases in several species, a figure entitled Density Gradient Centrifugation, and a section of text entitled "DNA repair requires energy."

KEY CONCEPTS

1. A series of experiments has shown that DNA is the genetic material.
2. DNA is a double-stranded helix in which the strands are antiparallel and the bases are held together by hydrogen bonding. Each of the four bases pairs with its complement: A with T and C with G. This structure accounts for the genetic information, mutation, and replication functions of DNA.
3. Many proteins, most notably DNA polymerases, assist in DNA replication.
4. The replication of DNA is semiconservative and proceeds in both directions from each origin of replication. The leading strand grows continuously, but synthesis of the lagging strand is discontinuous.
5. Errors in DNA replication are repaired by three different mechanisms: proofreading, mismatch repair, and excision repair.
6. Telomeres comprise the ends of eukaryotic chromosomes and are important in maintaining chromosomal stability. Loss of telomeres due to the activity of the enzyme telomerase is associated with aging and with cancers.
7. The principles of DNA replication can be applied to determine the nucleotide sequence of DNA.
8. The polymerase chain reaction technique uses DNA polymerases to repeatedly replicate DNA.

CHAPTER OUTLINE

I. DNA: The Genetic Material

A. DNA from one type of bacterium genetically transforms another type
B. The transforming principle is DNA
C. Viral replication experiments confirm that DNA is the genetic material

II. The Structure of DNA

A. X-ray crystallography provided clues to DNA structure
B. The chemical composition of DNA was known
C. Watson and Crick described the double helix
D. Four key features define DNA structure
E. The double helical structure of DNA is essential to its function

III. Determining the DNA Replication Mechanism

A. Three modes of DNA replication appeared possible
B. Meselson and Stahl demonstrated that DNA replication is semiconservative

IV. The Molecular Mechanisms of DNA Replication

A. DNA is threaded through a replication complex
B. Small, circular DNAs replicate from a single origin
C. Large, linear DNAs have many origins
D. DNA polymerases need a primer
E. Cells contain several different DNA polymerases
F. The lagging strand is synthesized from Okazaki fragments
G. Telomeres are not fully replicated

V. DNA Proofreading and Repair

A. Proofreading mechanisms ensure that DNA replication is accurate
B. Mismatch repair mechanisms correct base-pairing errors
C. Excision repair mechanisms repair chemical damage

VI. Practical Applications of DNA Replication

A. The polymerase chain reaction makes multiple copies of DNA
B. The nucleotide sequence of DNA can be determined

KEY TERMS

adenine (A)
antiparallel
complementary base pairing
cytosine (C)
DNA helicase
DNA ligase
DNA polymerase
DNA sequencing
DNA topoisomerase
excision repair
guanine (G)
helical
lagging strand
leading strand
mismatch repair
Okazaki fragments
origin of replication
polymerase chain reaction (PCR)
primer
proofreading
replication complex
replication forks
RNA primase
semiconservative replication
single strand binding proteins
telomerase
telomeres
template
thymine (T)
transforming principle

12 From DNA to Protein: Genotype to Phenotype

OVERVIEW

The chapter opens with a description of the studies that led to and support the one-gene, one-polypeptide hypothesis. Then protein synthesis is discussed, including detailed descriptions of RNA, transcription, translation, and posttranslational events. The chapter concludes with a discussion of the various types of mutations and their evolutionary significance.

WHAT'S NEW

Chapter 12 includes several changes. The authors have rewritten the descriptions of the Beadle and Tatum experiments for greater clarity and detail. The section called "Initiation of transcription requires a promoter and RNA polymerase" has been condensed, and new information on the role of ribosomes in ensuring the precision of mRNA–tRNA interactions has been included.

KEY CONCEPTS

1. Genes are made up of DNA and are expressed in the phenotype as polypeptides (proteins).
2. The one-gene, one-polypeptide hypothesis states that the function of a gene is to control the production of a single, specific polypeptide.
3. The central dogma of molecular biology is DNA → RNA → protein.
4. A gene is expressed in two steps: First, DNA is transcribed to RNA; then RNA is translated into protein.
5. RNA is transcribed from a DNA template after the bases of DNA are exposed by unwinding of the double helix. The initiation of transcription requires that RNA polymerase recognize and bind tightly to a promoter sequence on DNA. RNA elongates in its 5′-to-3′ direction and is antiparallel to the template DNA.
6. The genetic code consists of triplets of nucleotides (codons). One mRNA codon indicates the starting point of translation and codes for methionine. Three stop codons indicate the end of translation. The other 60 codons code only for particular amino acids.
7. The genetic code is redundant, but it is not ambiguous.
8. In prokaryotes, translation begins before the mRNA is completed. In eukaryotes, transcription occurs in the nucleus and translation occurs in the cytoplasm.
9. In translation, amino acids are linked in an order specified by the codons in mRNA. The aminoacyl-tRNA synthetases attach specific amino acids to their appropriate tRNAs, forming charged tRNAs. The mRNA meets the charged tRNAs at a ribosome and the amino acids are bound together in the correct sequence.
10. Some antibiotics work by blocking events in translation.
11. In a polysome, more than one ribosome moves along the mRNA at one time.

12. Protein synthesis begins on free ribosomes in the cytoplasm. Those proteins destined for the nucleus, mitochondria, and plastids are completed there and have signals that allow them to bind to and enter their destined organelles.
13. Proteins destined for the ER, Golgi apparatus, lysosomes, and outside the cell complete their synthesis on the surface of the ER.
14. Covalent modifications of proteins after translation include proteolysis, glycosylation, and phosphorylation.
15. Mutations in DNA are often expressed as abnormal proteins. However, the result may not be easily observable phenotypic changes. Some mutations appear only under certain conditions, such as exposure to a certain environmental agent (such as a drug) or condition (such as temperature).
16. Point mutations (silent, missense, nonsense, or frame-shift) result from alterations in single base pairs of DNA.
17. Chromosomal mutations (deletions, duplications, inversions, or translocations) involve large regions of a chromosome.
18. Mutations can be spontaneous or induced.
19. Mutations are the raw material of evolution.

CHAPTER OUTLINE

I. One Gene, One Polypeptide

II. DNA, RNA, and the Flow of Information
- A. RNA differs from DNA
- B. Information flows in one direction when genes are expressed
- C. RNA viruses modify the central dogma

III. Transcription: DNA-Directed RNA Synthesis
- A. Initiation of transcription requires a promoter and RNA polymerase
- B. RNA polymerase elongates the transcript
- C. Transcription terminates at particular base sequences

IV. The Genetic Code
- A. The genetic code is redundant but not ambiguous
- B. The genetic code is (nearly) universal
- C. Biologists deciphered the genetic code by using artificial messengers

V. Preparation for Translation: Linking RNAs, Amino Acids, and Ribosomes
- A. Activating enzymes link the right tRNAs and amino acids
- B. The ribosome is the workbench for translation

VI. Translation: RNA-Directed Polypeptide Synthesis
- A. Translation begins with an initiation complex
- B. The polypeptide elongates from the N terminus
- C. Elongation continues and the polypeptide grows
- D. A release factor terminates translation

VII. Regulation of Translation
- A. Some antibiotics and bacterial toxins work by inhibiting translation
- B. Polysome formation increases the rate of protein synthesis

VIII. Posttranslational Events
- A. Chemical signals in proteins direct them to their cellular destinations
- B. Many proteins are modified after translation

IX. Mutations: Heritable Changes in Genes
- A. Chromosomal mutations are extensive changes in the genetic material
- B. Mutations can be spontaneous or induced
- C. Mutations are the raw material of evolution

KEY TERMS

anticodon
central dogma
chromosomal mutations
codon
conditional mutants
deletions
duplications
elongation
elongation factors
frame-shift mutations
germ line mutations
glycosylation
induced mutations
initiation
initiation complex
inversions
messenger RNA (mRNA)
missense mutations
mutations
nonsense mutations
phosphorylation
point mutations
polyribosome
polysome
promoter
proteolysis
retroviruses
RNA (ribonucleic acid)
RNA polymerase
signal recognition particle
signal sequences
silent mutations
somatic mutations
spontaneous mutations
start codon
stop codons
termination
transcription
transfer RNA (tRNA)
translation
translocations
uracil (U)