

23

Metabolism, Nutrition, and Energetics

Lecture Presentation by
Lori Garrett

Section 1: Introduction to Cellular Metabolism

Learning Outcomes

- 23.1 Define metabolism, catabolism, and anabolism, and give an overview of cellular metabolism.
- 23.2 Describe the role of the nutrient pool in cellular metabolism.
- 23.3 Summarize the important events and products of glycolysis.
- 23.4 Describe the basic steps in the citric acid cycle.

Section 1: Introduction to Cellular Metabolism

Learning Outcomes (continued)

- 23.5 Describe the basic steps in the electron transport chain.
- 23.6 Identify the sources of ATP production and energy yield at each source during glucose catabolism.
- 23.7 Define glycogenesis, glycogenolysis, and gluconeogenesis.

Module 23.1: Metabolism is the sum of catabolic and anabolic reactions

Metabolism

- Sum of all chemical reactions that occur in an organism
 - **Catabolism**
 - Breakdown of organic substrates in the body
 - **Anabolism**
 - Synthesis of new organic molecules
 - Can make use of nutrient pool from blood
- **Cellular metabolism**
 - Chemical reactions within cells

Module 23.1: Overview of cellular metabolism

Metabolism (continued)

■ Metabolic turnover

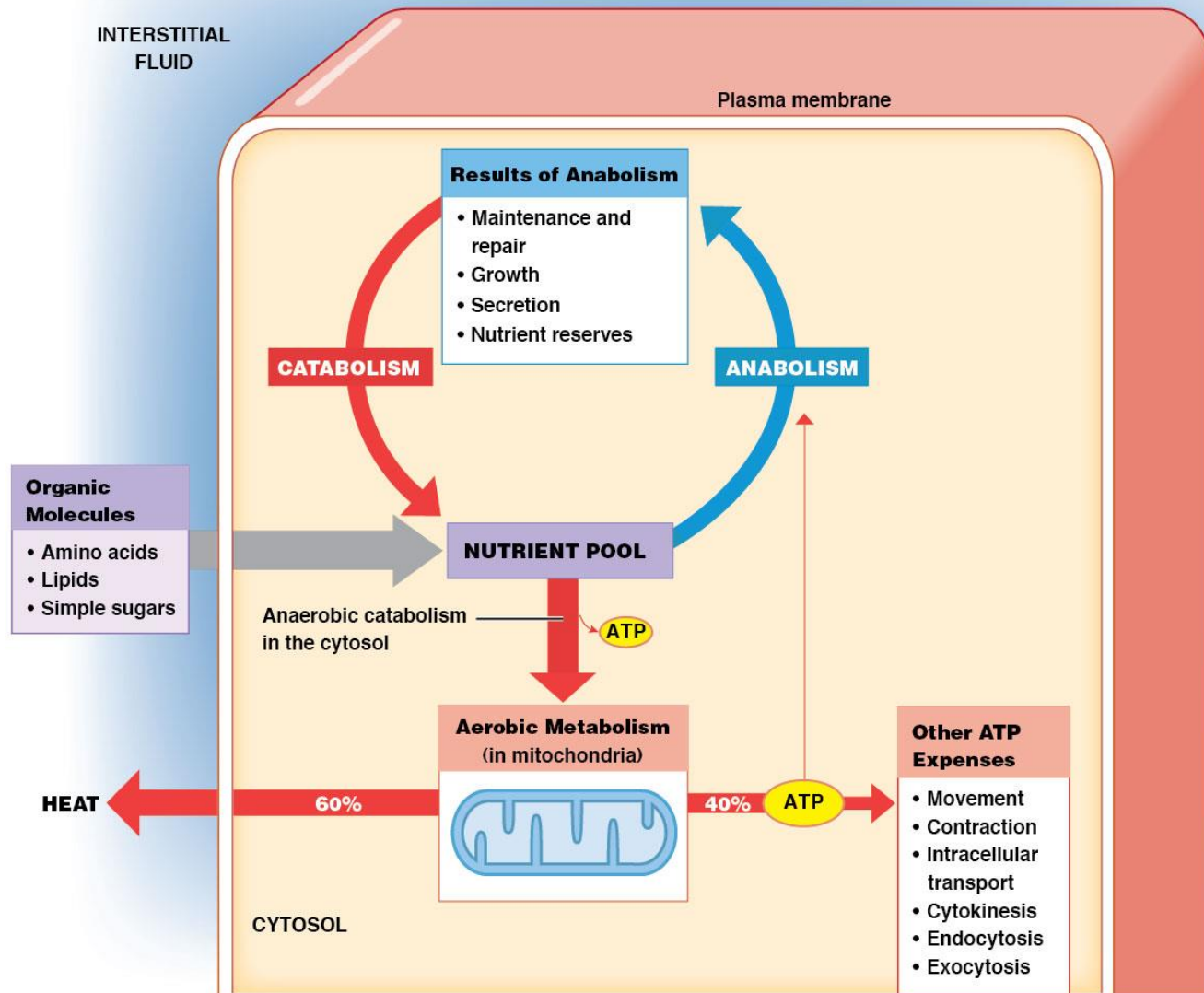
- Process of continual breakdown and replacement of all cellular organic components except DNA
- Cells obtain building blocks from:
 - Catabolic reactions
 - Absorption of organic molecules from the surrounding interstitial fluids
- Both processes create an accessible source of organic substrates called a **nutrient pool**

Module 23.1: Overview of cellular metabolism

Metabolism (continued)

- Cellular catabolism (**aerobic metabolism**)
 - Occurs in the mitochondria
 - 40 percent of energy is captured
 - Used to convert adenosine diphosphate (ADP) to adenosine triphosphate (ATP)
 - ATP is used for anabolism and other cellular functions
 - 60 percent of energy escapes as heat
 - Warms the interior of the cell and the surrounding tissue

An overview of cellular metabolism



Module 23.1: Review

- A. Compare catabolism and anabolism.
- B. Explain the process of metabolic turnover.

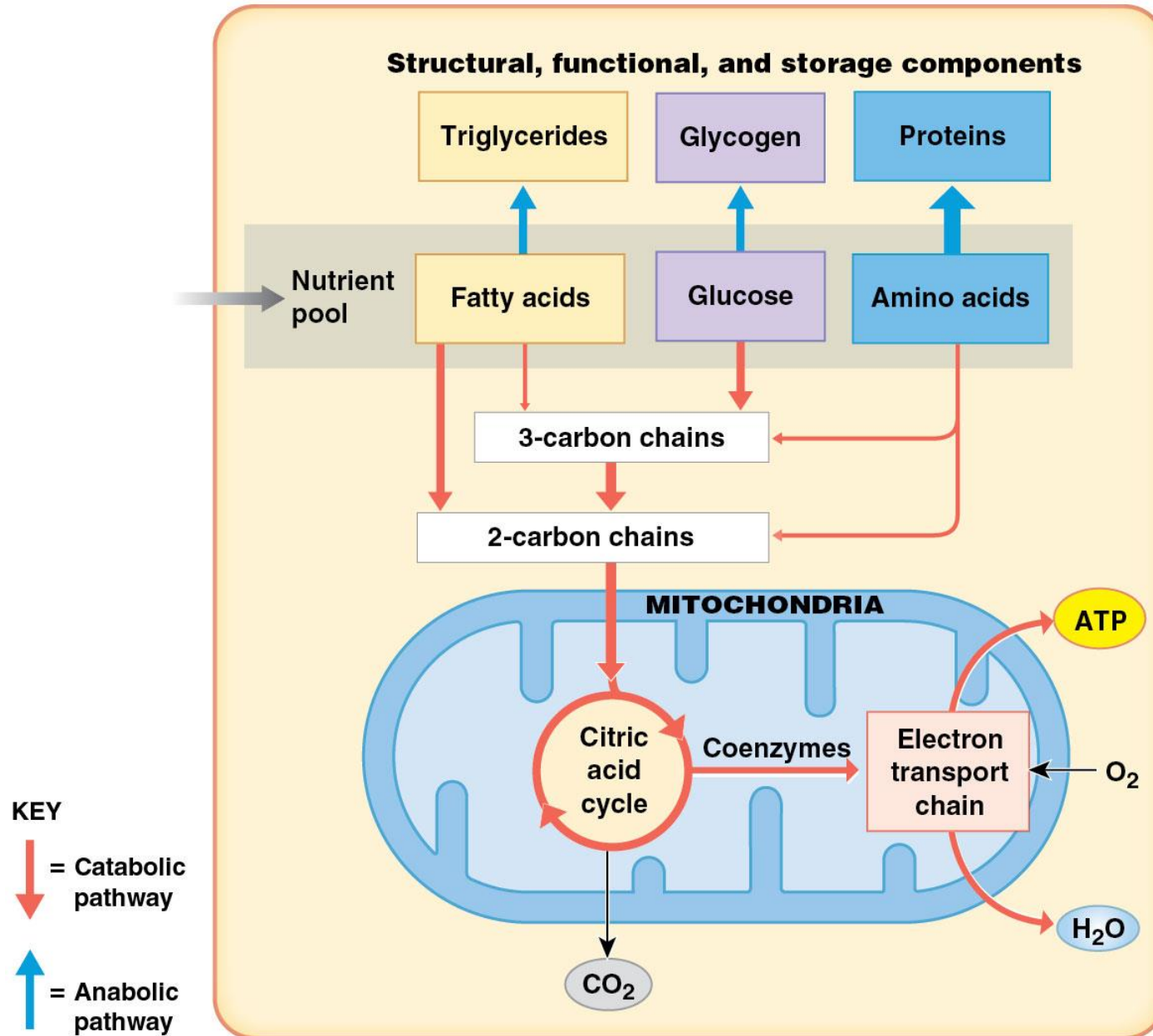
Learning Outcome: Define metabolism, catabolism, and anabolism, and give an overview of cellular metabolism.

Module 23.2: Cells use nutrients from the nutrient pool for metabolism

Nutrient pool

- Source for organic substrates (molecules) for both catabolism and anabolism
- Anabolism in the cell required for:
 - Replacing membranes, organelles, enzymes, and structural proteins
- Catabolism in the cell required for:
 - Converting substrates to a 2-carbon molecule
 - Utilized by mitochondria to produce ATP

The nutrient pool



Module 23.2: The nutrient pool

Mobilization of metabolic reserves

- Reserves are mobilized when absorption across the digestive tract is insufficient to maintain normal nutrient levels
 - Liver cells break down triglycerides and glycogen
 - Fatty acids and glucose can be released
 - Adipocytes break down triglycerides
 - Fatty acids can be released
 - Skeletal muscle cells break down contractile proteins
 - Amino acids can be released

Module 23.2: The nutrient pool

Restoration of metabolic reserves

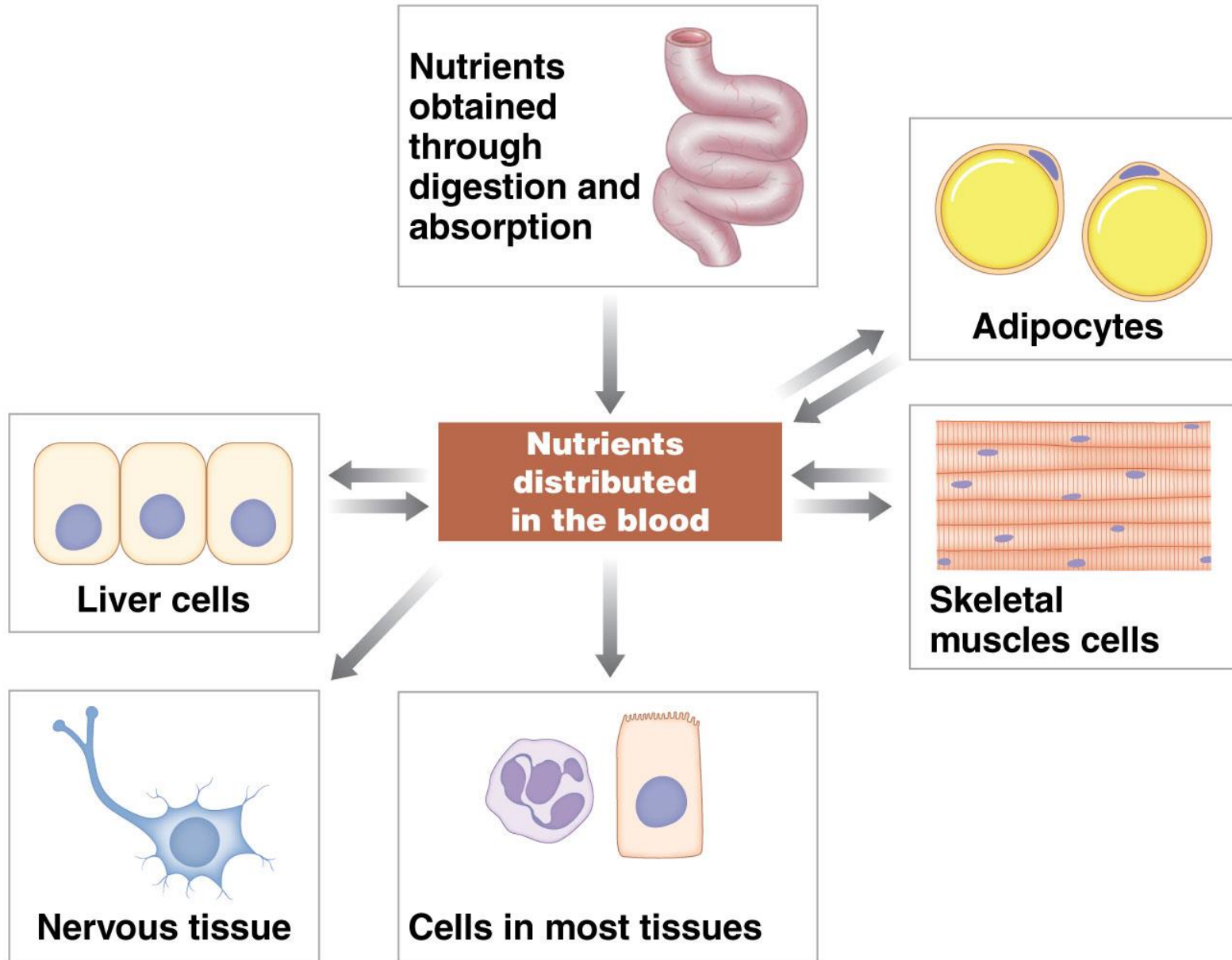
- Reserves are stocked when absorption by the digestive tract is greater than immediate nutrient needs
 - Liver cells store triglycerides and glycogen
 - Adipocytes convert excess fatty acids to triglycerides
 - Skeletal muscles build glycogen reserves and use amino acids to increase numbers of myofibrils

Module 23.2: The nutrient pool

Utilization of resources

- Cells in most tissues continuously absorb and catabolize glucose
- Nervous tissue must have a continuous supply of glucose
 - During starvation, other tissues can shift to fatty acid or amino acid catabolism
 - Conserves body's glucose for nervous tissue

The nutrient pool



Module 23.2: Review

- A. List the reactants required and products generated by mitochondria.

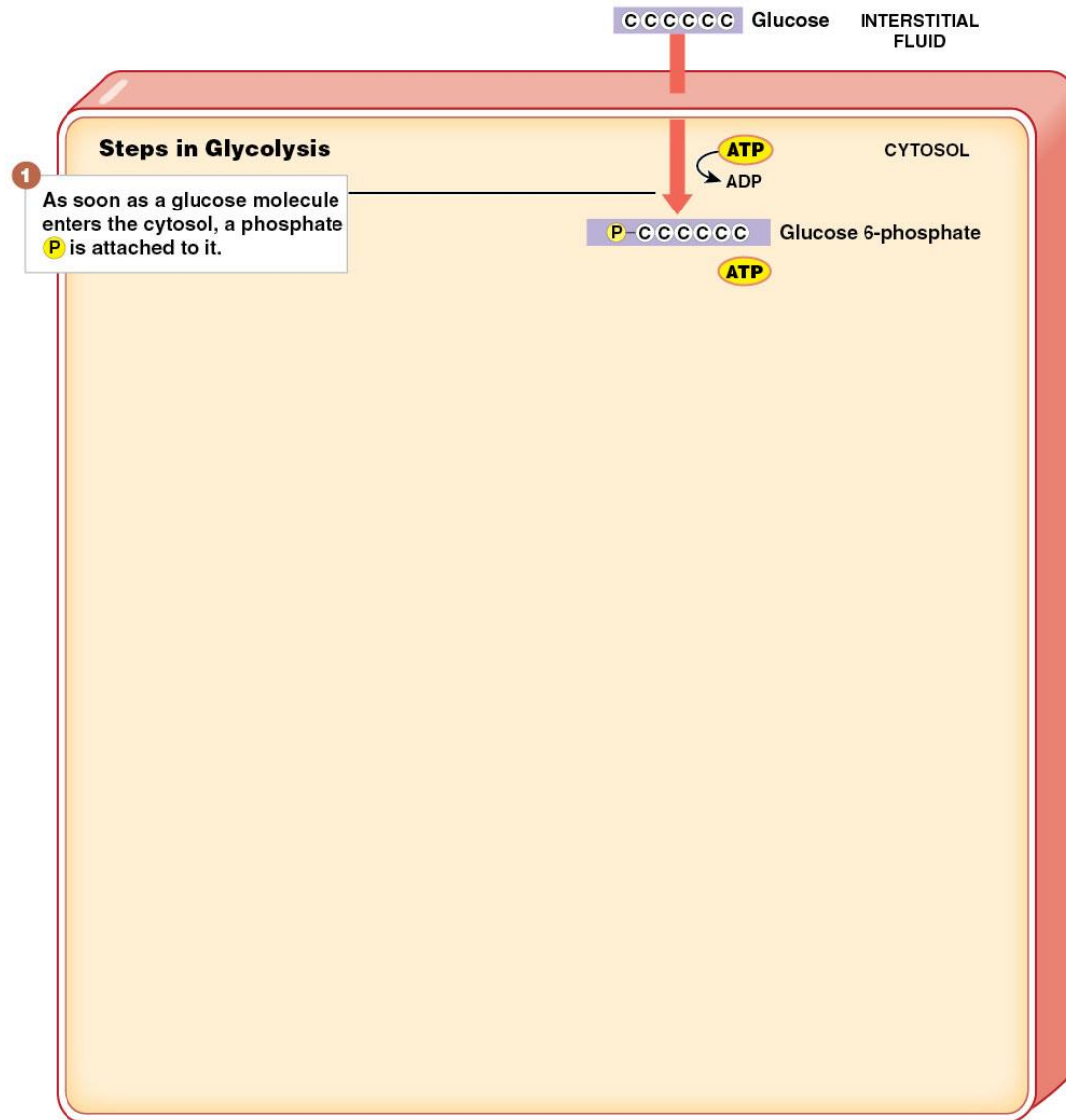
Learning Outcome: Describe the role of the nutrient pool in cellular metabolism.

Module 23.3: Glycolysis is the first step in glucose catabolism

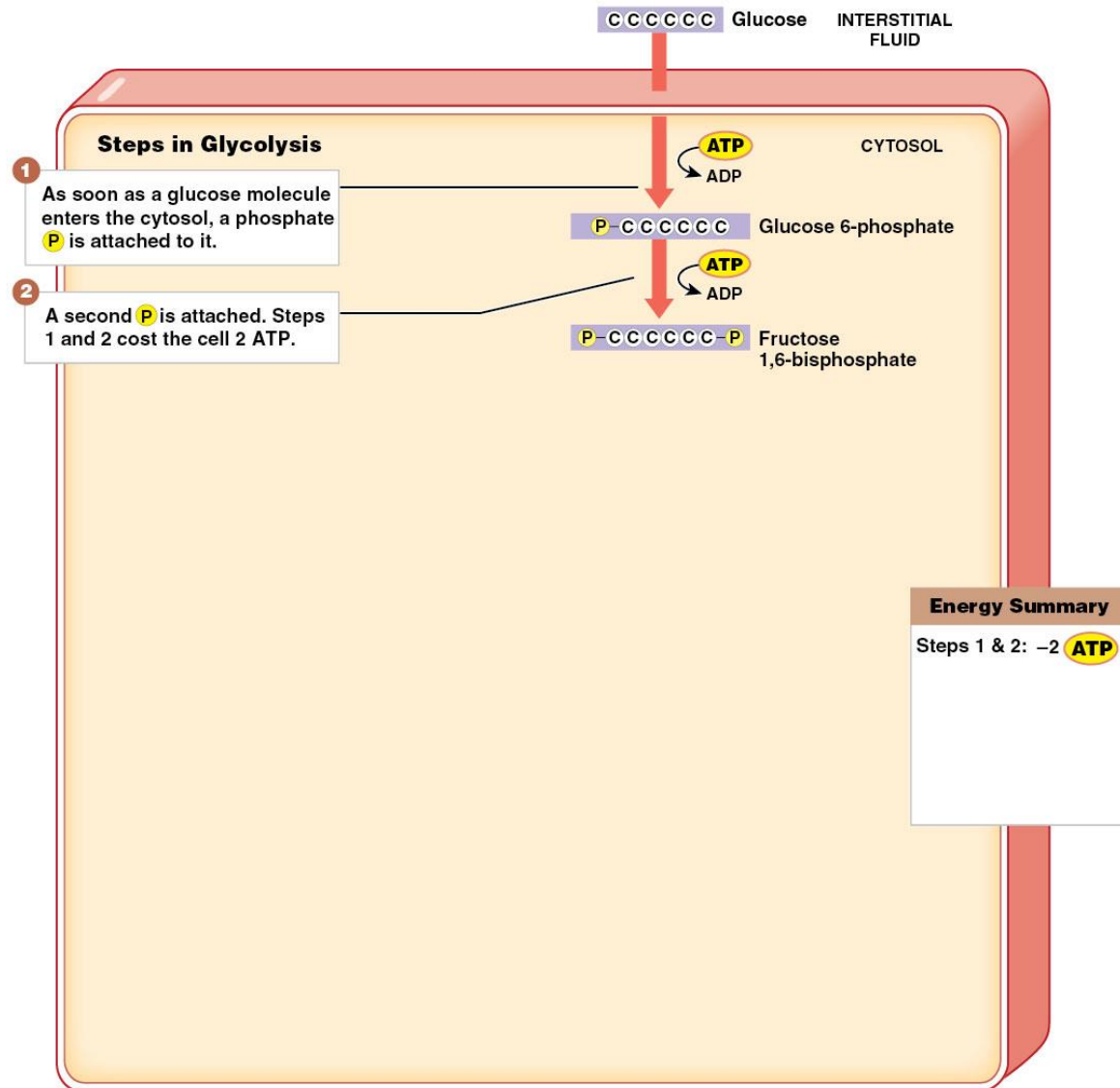
Glucose—preferred molecule for catabolism and ATP production

- **Glycolysis**—anaerobic process
 - Breaks down 6-carbon glucose to two 3-carbon pyruvates
 - Products: 2 net ATP, 2 pyruvate, 2 NADH (electron carriers)

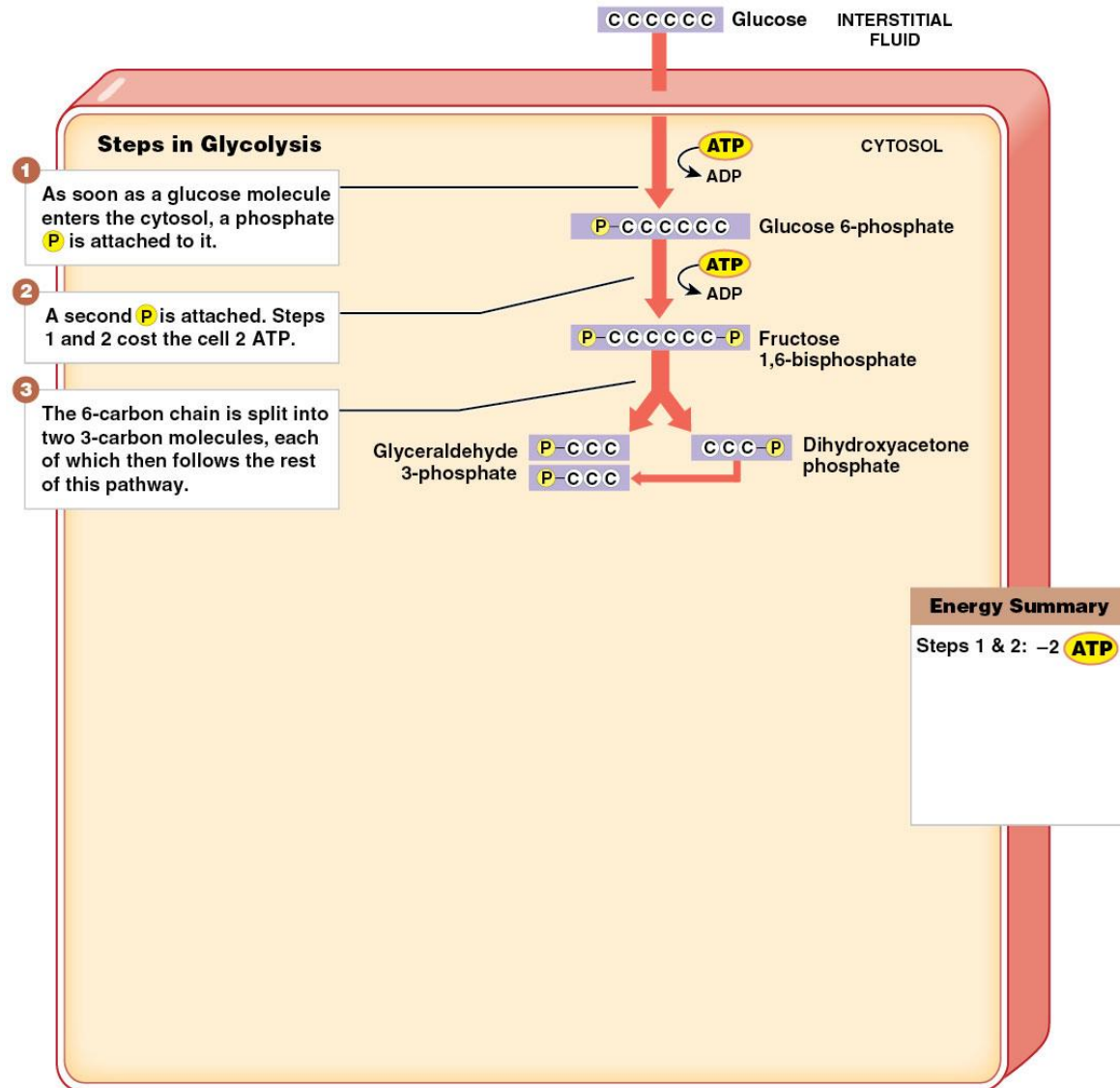
Steps in glycolysis



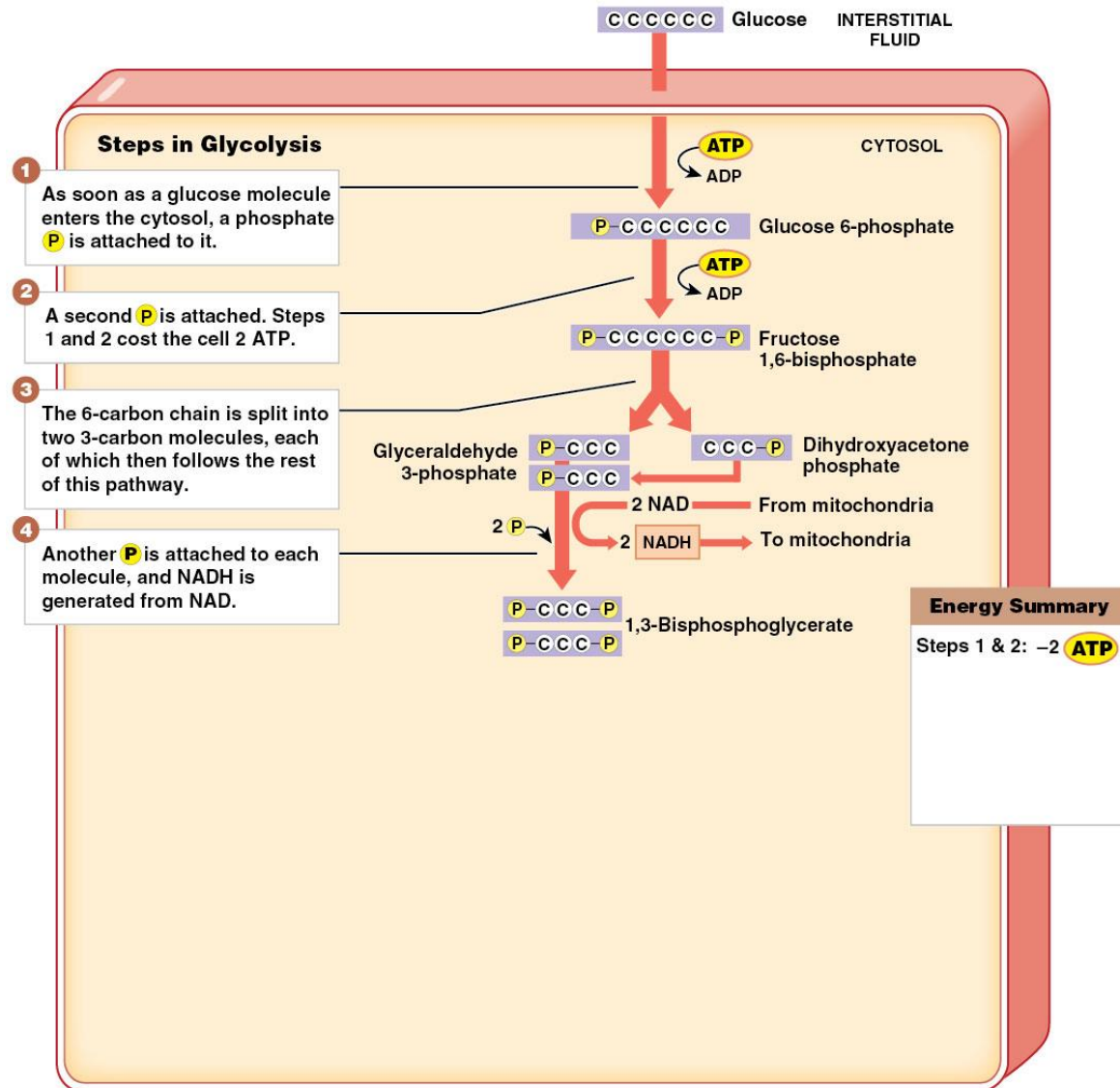
Steps in glycolysis



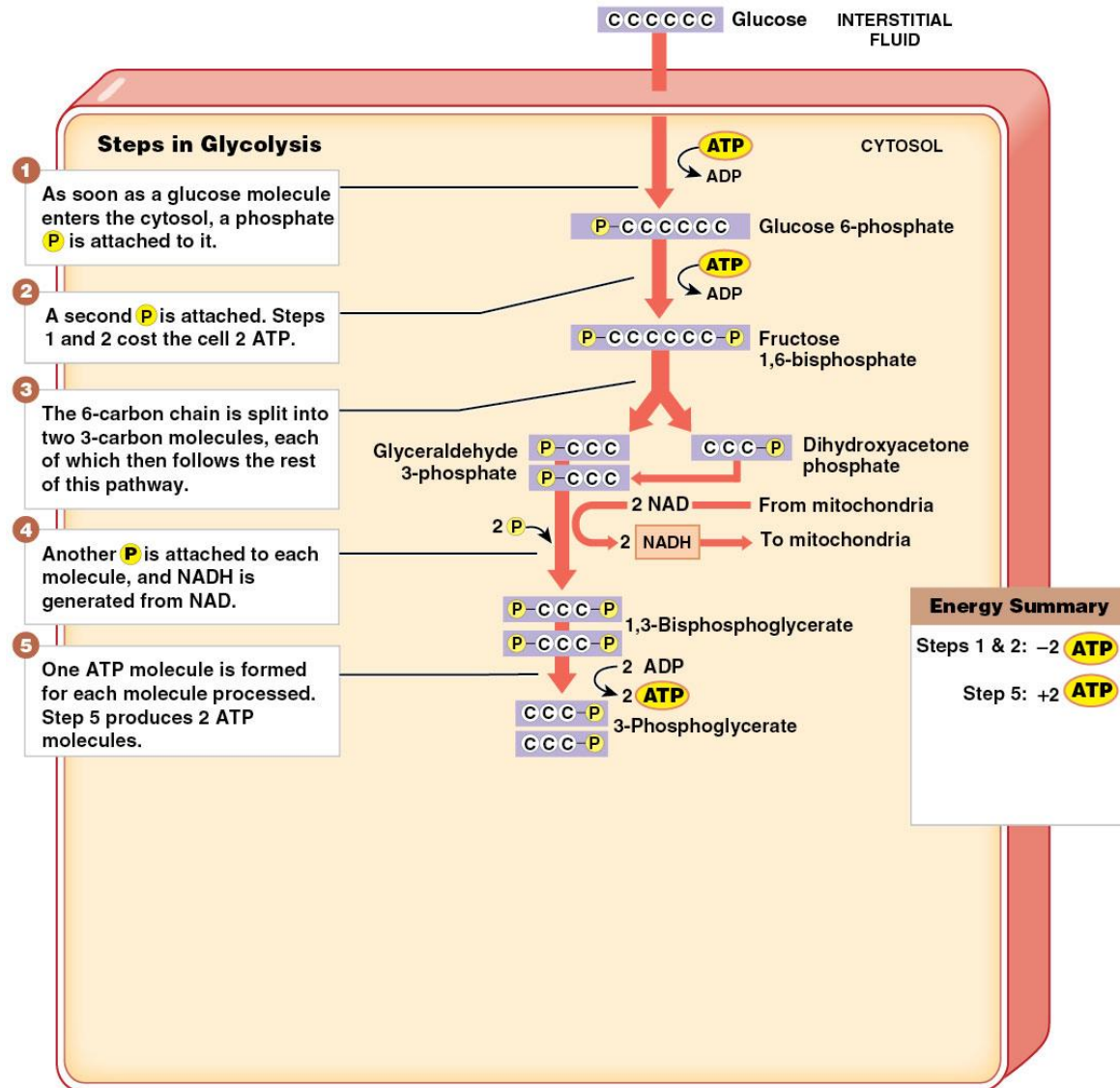
Steps in glycolysis



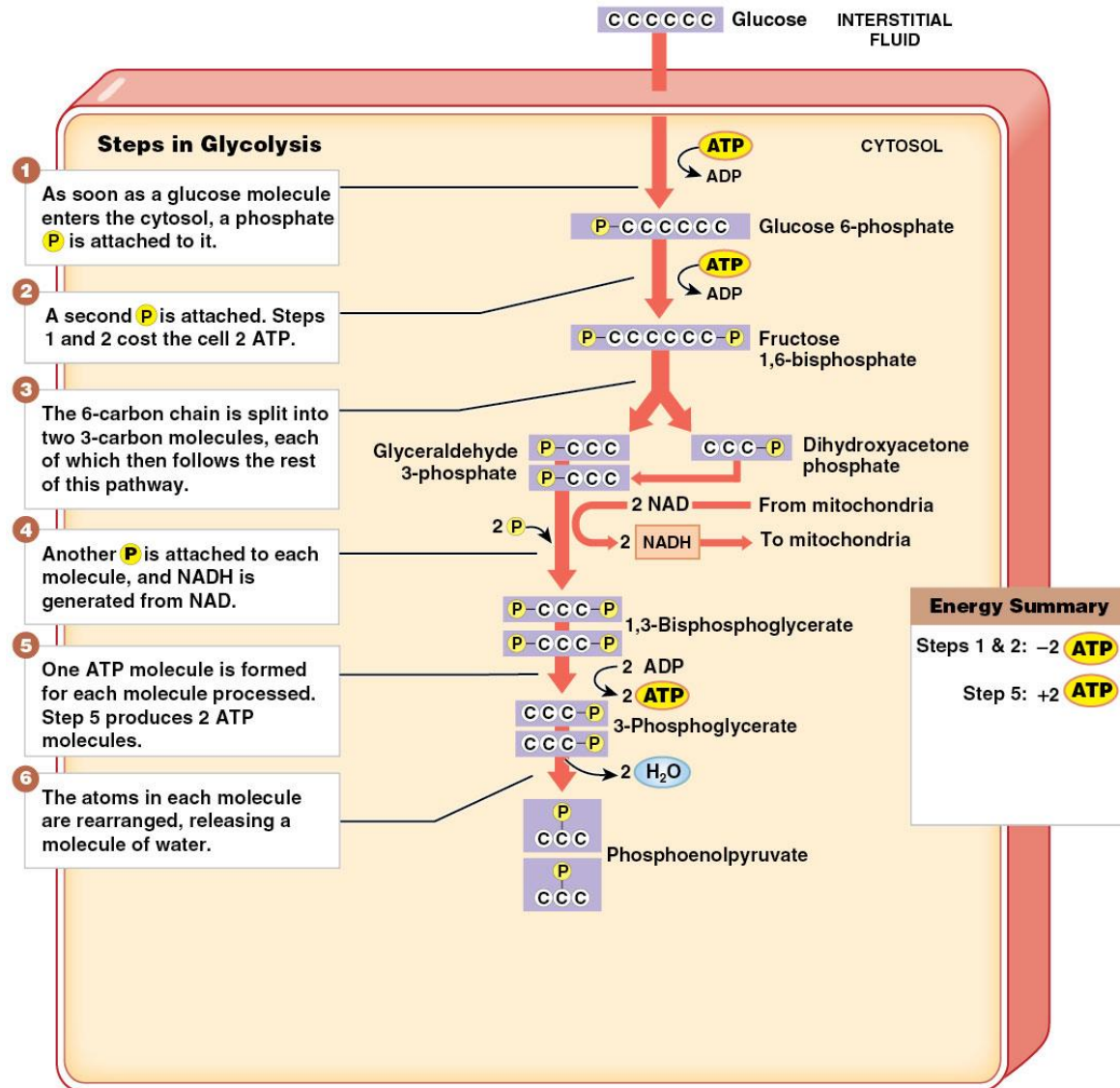
Steps in glycolysis



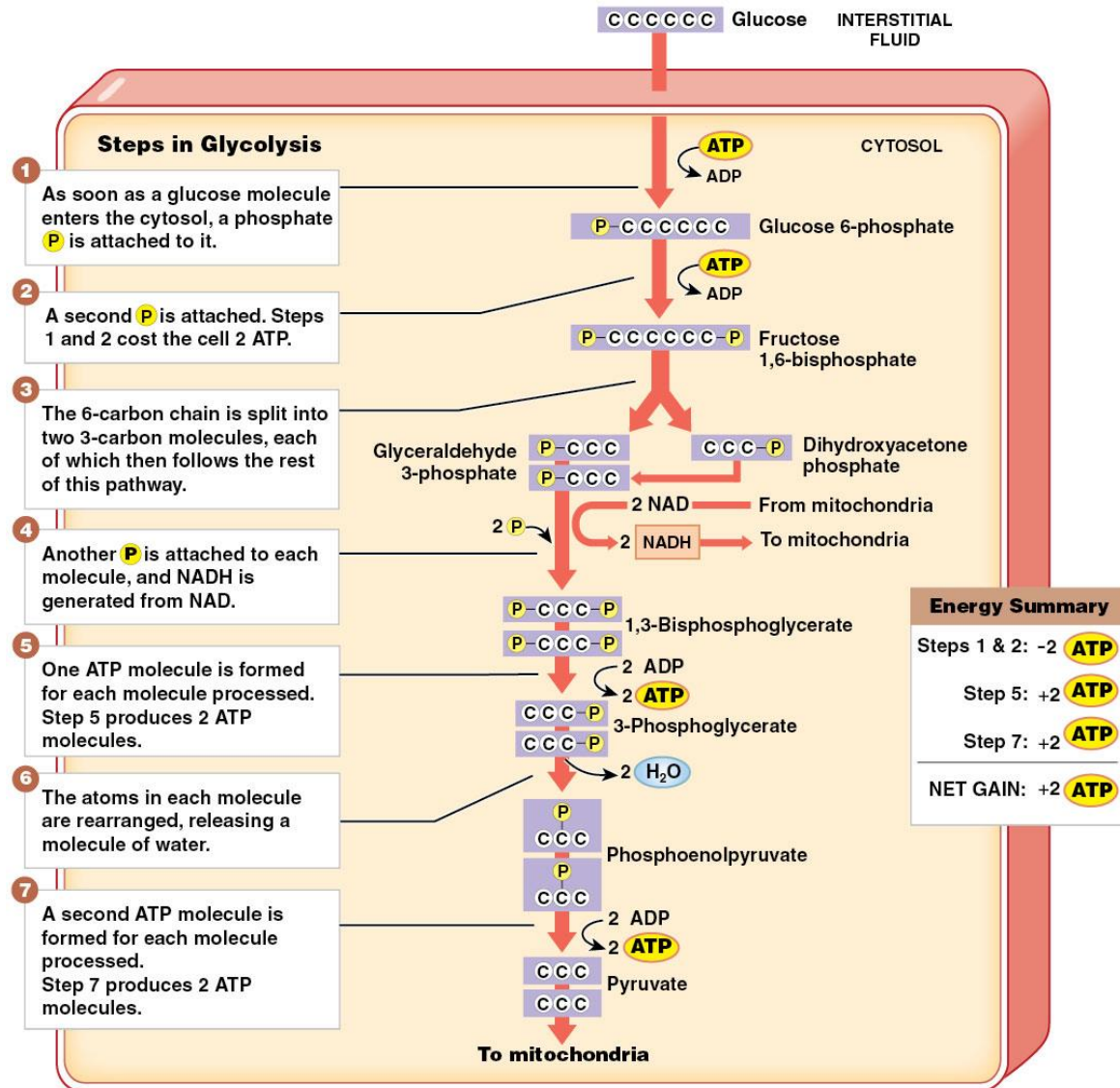
Steps in glycolysis



Steps in glycolysis



Steps in glycolysis



Module 23.3: Review

A. List the products of glycolysis.

Learning Outcome: Summarize the important events and products of glycolysis.

Module 23.4: The citric acid cycle transfers hydrogen atoms to coenzymes

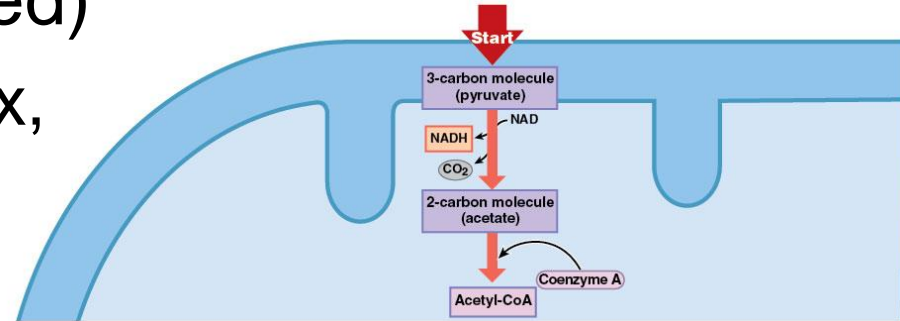
Citric acid cycle (Krebs cycle)

- **Aerobic metabolism**—requires oxygen
- Overall function is to remove hydrogen atoms from specific organic molecules and transfer them to coenzymes
- Process of cellular ATP production begins in the cytoplasm
 - Organic nutrients from the nutrient pool are broken into smaller 3-carbon and 2-carbon molecules

Module 23.4: The citric acid cycle

Citric acid cycle (continued)

- In the mitochondrial matrix, pyruvate (3-carbon molecule) is converted into a 2-carbon **acetate ion**

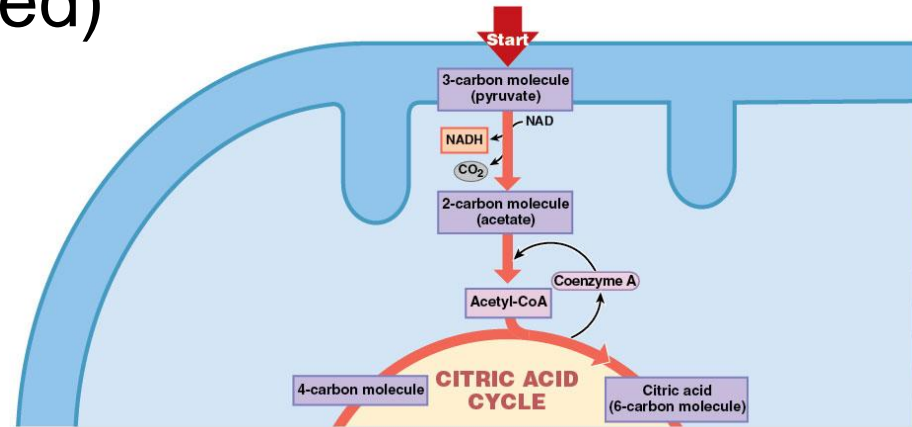


- In the process, 1 NADH, and 1 CO₂ are produced
- Common substrate for mitochondria is acetate
 - Attaches to coenzyme A to form acetyl-coenzyme A (**acetyl-CoA**)
 - This acetyl-CoA then enters the **citric acid cycle**

Module 23.4: The citric acid cycle

Citric acid cycle (continued)

- The **acetyl group** ($\text{—CH}_3\text{CO}$) from acetyl-CoA attaches to a 4-carbon molecule
 - Releases coenzyme A
 - Produces **citric acid** (a 6-carbon molecule)



Module 23.4: The citric acid cycle

Citric acid cycle (continued)

- In a series of reactions, hydrogen atoms are removed from organic molecules
 - Hydrogen atoms (and their electrons) are transferred to **coenzymes**
 - Two carbon atoms are lost as CO_2
 - Remaining 4-carbon molecule is then ready to receive another 2-carbon acetyl group from acetyl-CoA
 - Each cycle turn results in production of 1 ATP
 - Cycle turns twice per 1 glucose

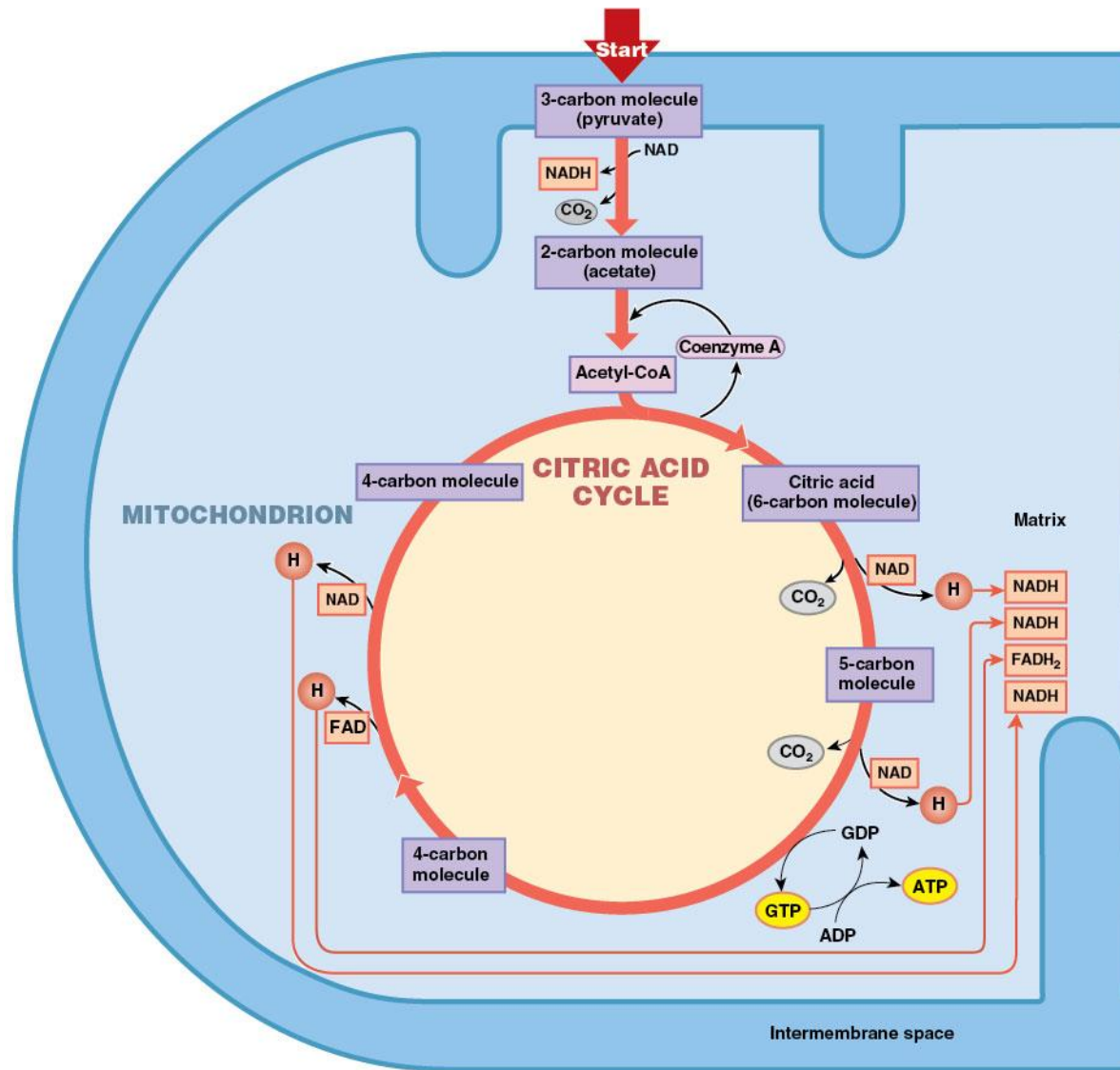
Module 23.4: The citric acid cycle

Citric acid cycle (continued)

■ Coenzymes

- Deliver hydrogen atoms to the **electron transport system (ETS)**
- **NAD** (*nicotinamide adenine dinucleotide*)
 - Each NAD can carry 1 hydrogen atom as NADH
- **FAD** (*flavin adenine dinucleotide*)
 - Each FAD can carry 2 hydrogen atoms as FADH₂

The citric acid cycle

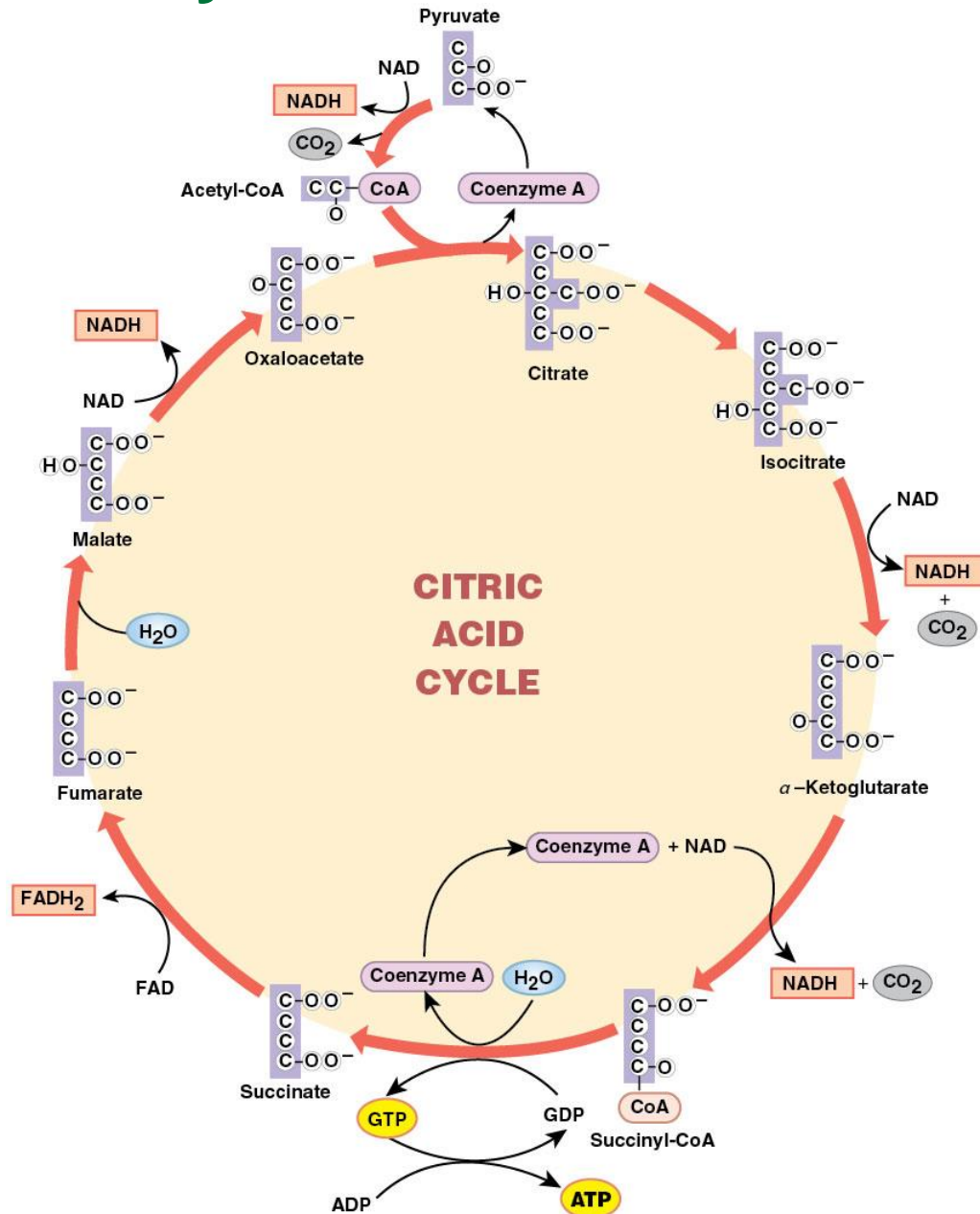


Module 23.4: The citric acid cycle

Summary

- For each acetyl-CoA molecule entering the citric acid cycle:
 - 5 hydrogen atoms are removed and transferred to coenzymes
 - 2 molecules of CO_2 are produced
 - 2 molecules of water are consumed
 - Net energy gain of 1 ATP
 - Guanosine triphosphate (GTP) is formed from Guanosine diphosphate (GDP)
 - Transfers a phosphate group to ADP, forming ATP

The citric acid cycle



Module 23.4: Review

- A. Briefly describe the citric acid cycle, and explain its role.
- B. What molecule forms the common substrate for the citric acid cycle?
- C. What two coenzymes transfer hydrogen atoms to the electron transport system?

Learning Outcome: Describe the basic steps in the citric acid cycle.

Module 23.5: The electron transport chain establishes a proton gradient used to make ATP

Oxidative phosphorylation

- Generation of ATP within mitochondria in a reaction sequence that requires coenzymes and consumes oxygen
 - *Oxidation* refers to the transfer of electrons
 - *Phosphorylation* refers to the attachment of a phosphate to ADP producing ATP
- Produces more than 90 percent of the ATP used by body cells

Module 23.5: The electron transport chain

Oxidative phosphorylation (continued)

- Key reactions occur in the **electron transport chain (ETC)**, or respiratory chain
- Oxygen is needed as the final electron acceptor
 - Lack of oxygen stops the ETC
 - Blocking cytochromes also stops the ETC
 - *Example:* poisons such as cyanide
 - With no functioning ETC, the citric acid cycle stops
 - Cells die from lack of ATP

Module 23.5: The electron transport chain

Steps in oxidative phosphorylation

1. Coenzymes deliver hydrogen atoms from the citric acid cycle to the ETC
 - Series of protein-pigment molecules called **cytochromes** (*cyto-*, cell + *chroma*, color) embedded in inner mitochondrial membrane
- The hydrogen atom is composed of:
 - A high-energy electron (e^-)
 - Given to the ETC
 - A hydrogen ion or proton (H^+)
 - Released into the mitochondrial matrix

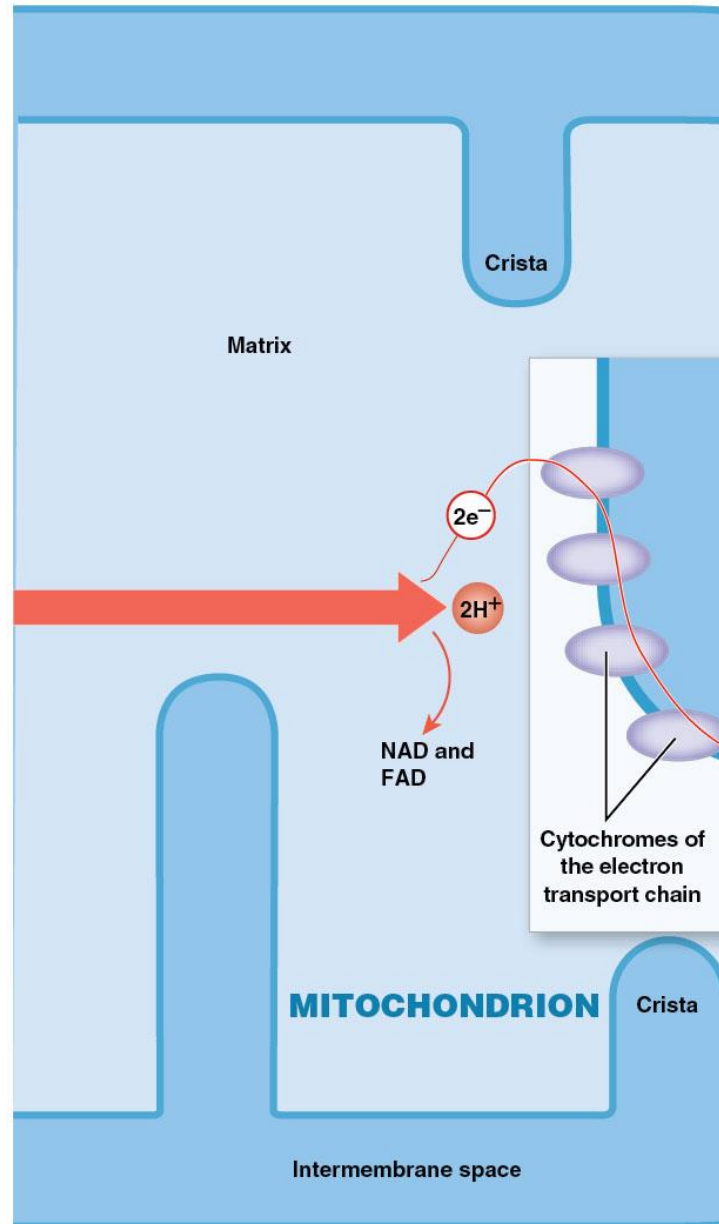
Module 23.5: The electron transport chain

Steps in oxidative phosphorylation (continued)

1. (continued)

- Oxidation-reduction (redox) reactions
 - Oxidation is the loss of electrons
 - Reduction is the gain of electrons

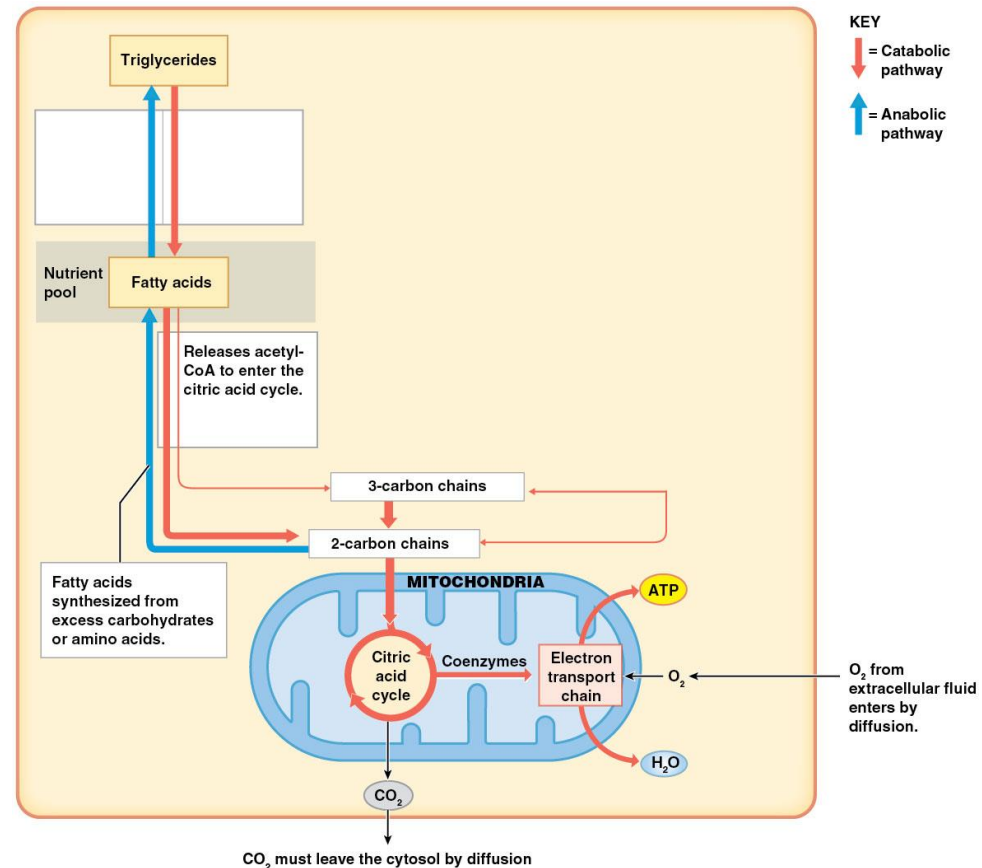
Oxidative phosphorylation



Module 23.5: The electron transport chain

Steps in oxidative phosphorylation (continued)

2. Cytochromes pass electrons sequentially down the chain of cytochromes
3. Released energy is used to pump hydrogen ions into the intermembrane space

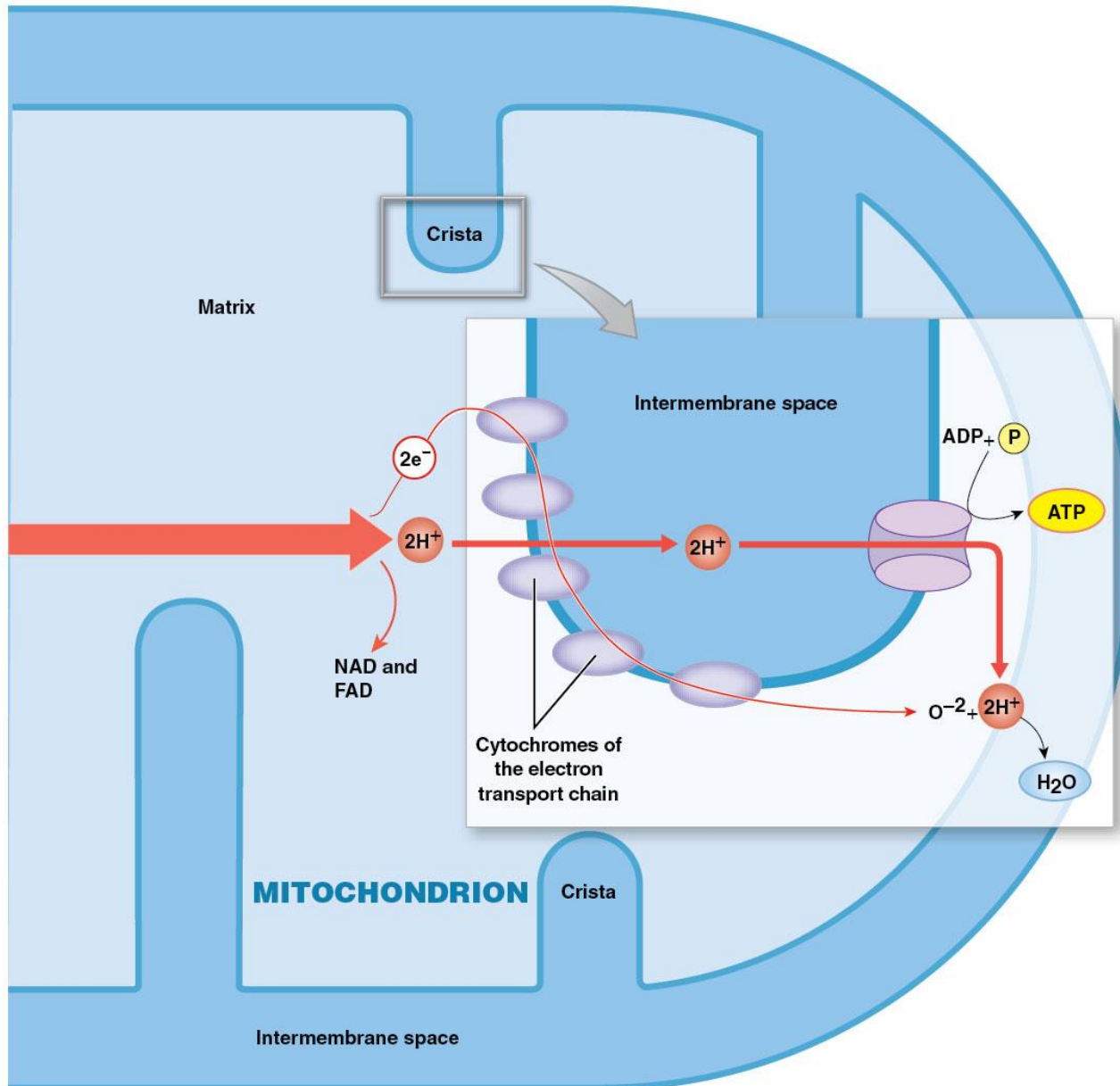


Module 23.5: The electron transport chain

Steps in oxidative phosphorylation (continued)

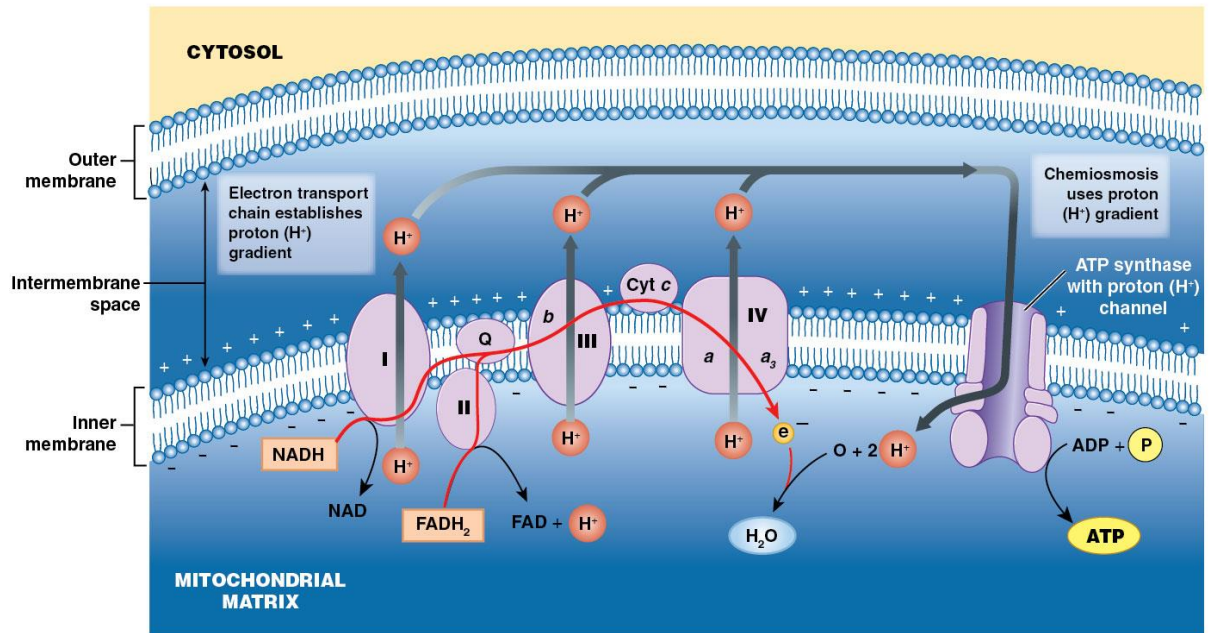
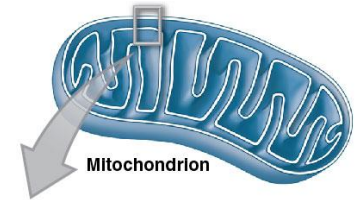
4. Hydrogen ions can diffuse back into the matrix only through specific hydrogen ion channels
 - Passage of the ions through these channels powers ATP production by **ATP synthase**
5. Oxygen is the final electron acceptor
 - Reacts with 2 hydrogen ions to form water

Oxidative phosphorylation

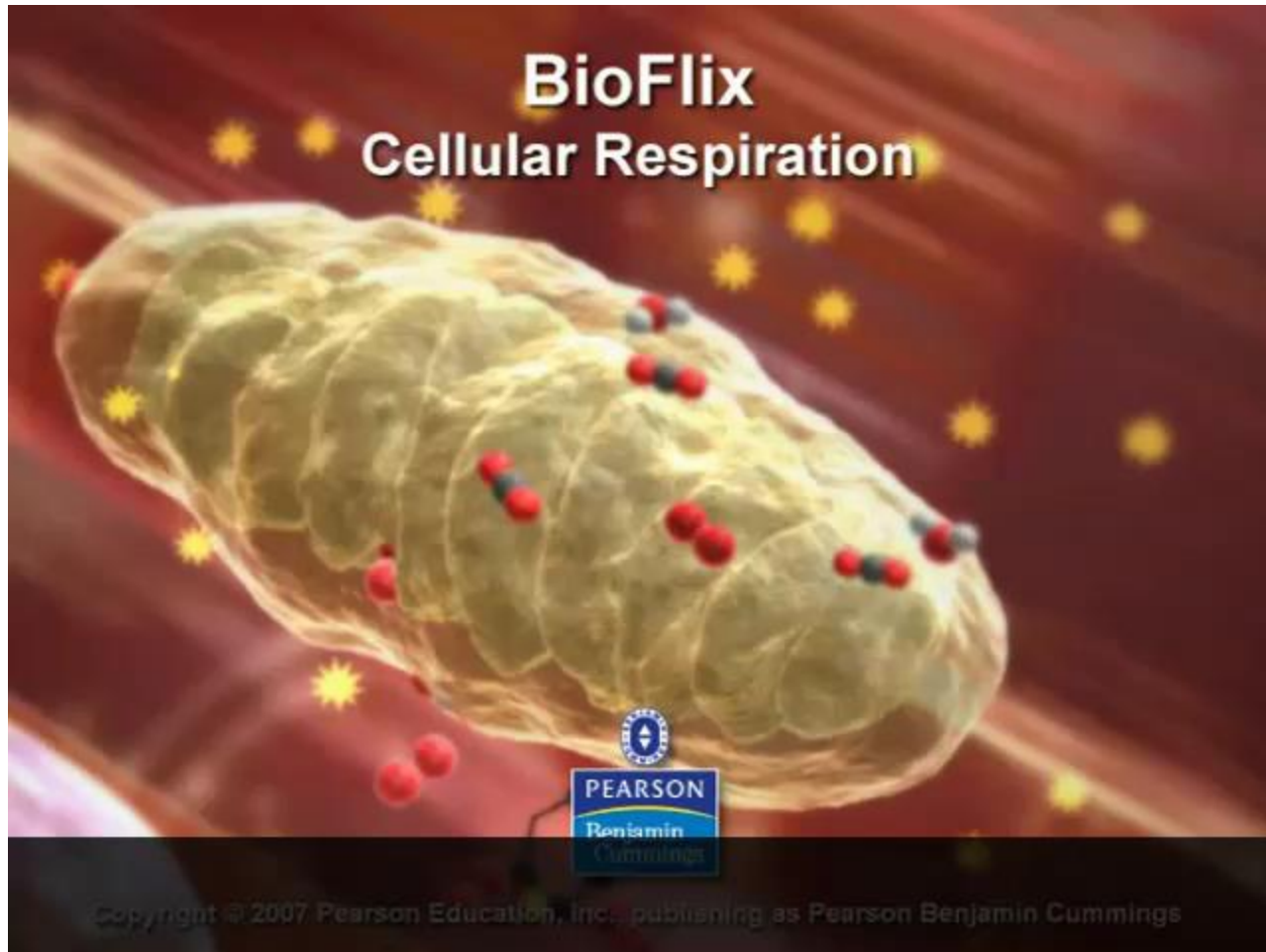


Module 23.5: The electron transport chain

- In oxidative phosphorylation, final electron acceptor is oxygen; water forms
- ETC has 4 respiratory complexes, coenzyme Q, and cytochromes *b*, *c*, *a*, and *a*₃
- Proton gradient generated by ETC leads to **chemiosmosis**



BioFlix: Cellular Respiration



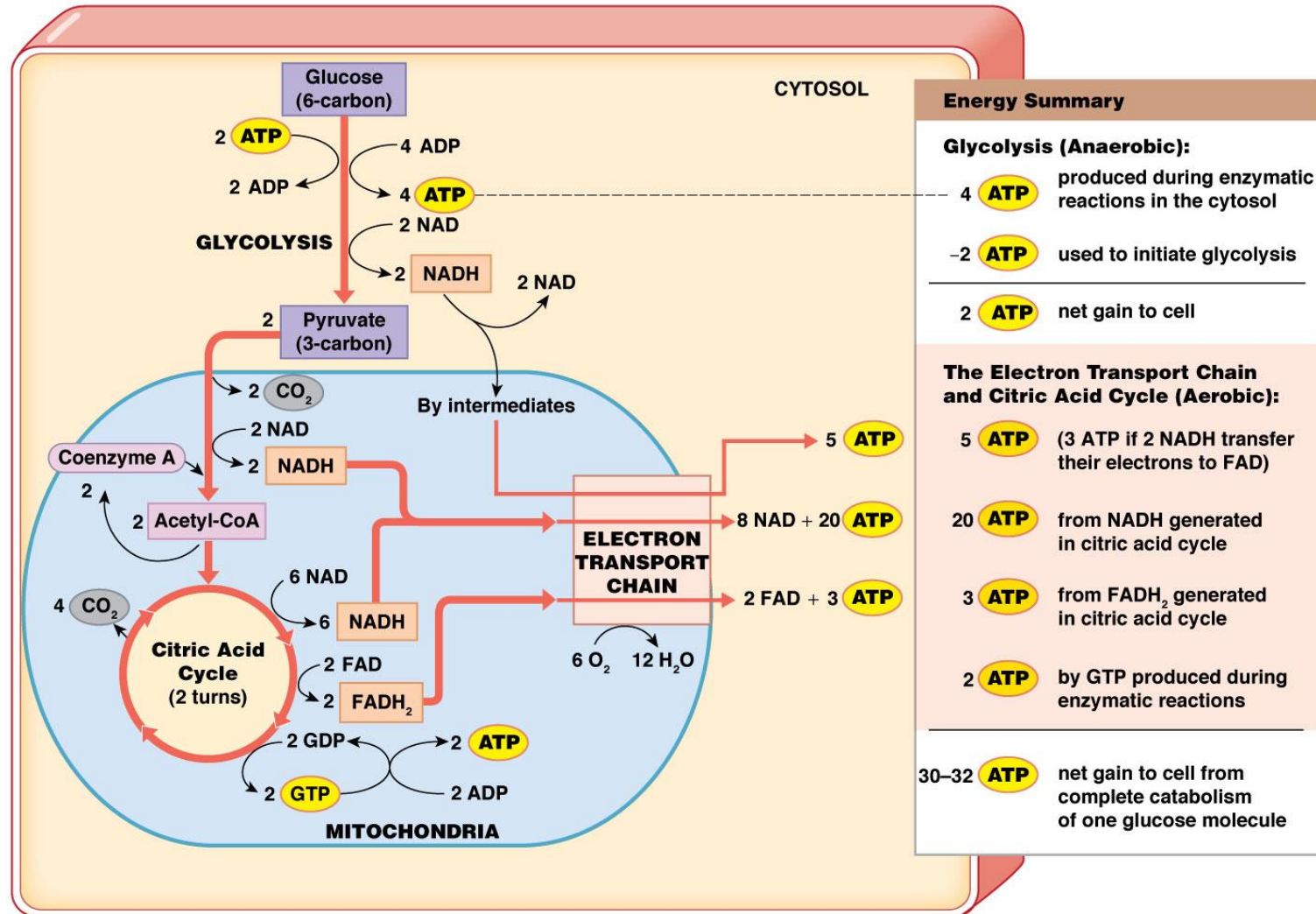
Module 23.5: Review

- A. Define *oxidative phosphorylation*.
- B. Compare oxidation and reduction.
- C. Describe the role that hydrogen ion channels play in the generation of ATP.

Learning Outcome: Describe the basic steps in the electron transport chain.

Glucose catabolism yields 30–32 ATP

1 molecule of glucose generates 30–32 molecules of ATP



Reasons Why Glucose Is the Primary Energy Source for Cells

- Glucose is a small, soluble molecule that is easily distributed through body fluids.
- Glucose can provide ATP anaerobically through glycolysis. Although only a small amount of ATP is produced, glycolysis is important during peak levels of physical activity, in red blood cells, or when a tissue is temporarily deprived of oxygen.
- Glucose can be stored as glycogen, which forms compact, insoluble granules.
- Glucose can be easily mobilized because the breakdown of glycogen (glycogenolysis) occurs very quickly and involves only a single enzymatic step. Mobilization of other intracellular reserves involves much more complex pathways and takes considerably more time.

Module 23.6: Review

- A. Identify when most of the CO_2 is released during the complete catabolism of glucose.
- B. Explain when glycolysis is important in cellular metabolism.

Learning Outcome: Identify the sources of ATP production and energy yield at each source during glucose catabolism.

Module 23.7: Nutrient metabolism follows several pathways

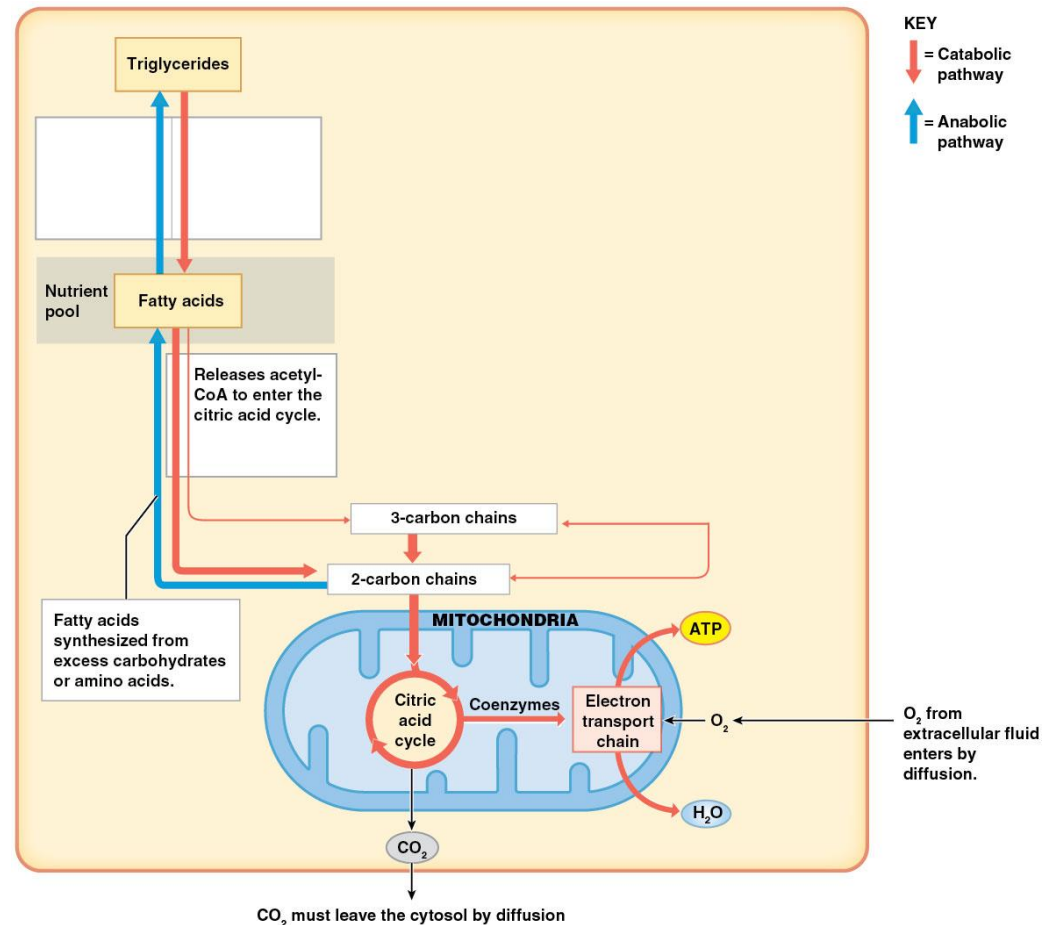
The diet and nutrient pools do not provide all building blocks for proteins, carbohydrates, and lipids

- Cellular enzymes synthesize them

Module 23.7: Nutrient metabolism pathways

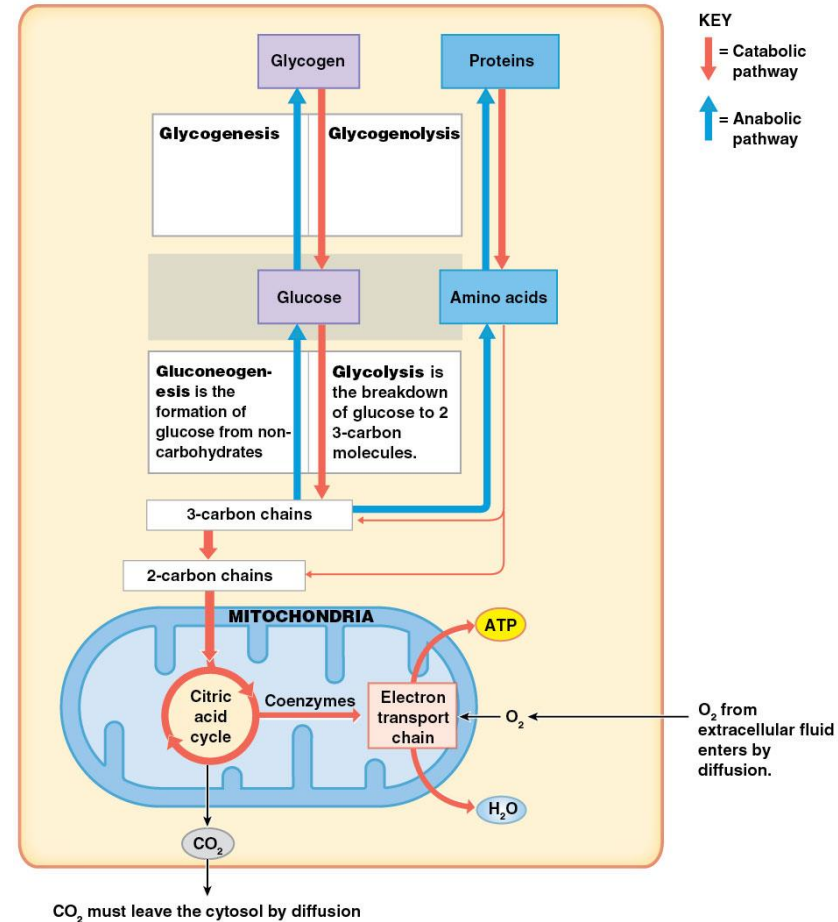
Fatty acids stored as triglycerides can be broken down into glycerol and fatty acids

- Breakdown of fatty acid releases acetyl- CoA, which enters citric acid cycle



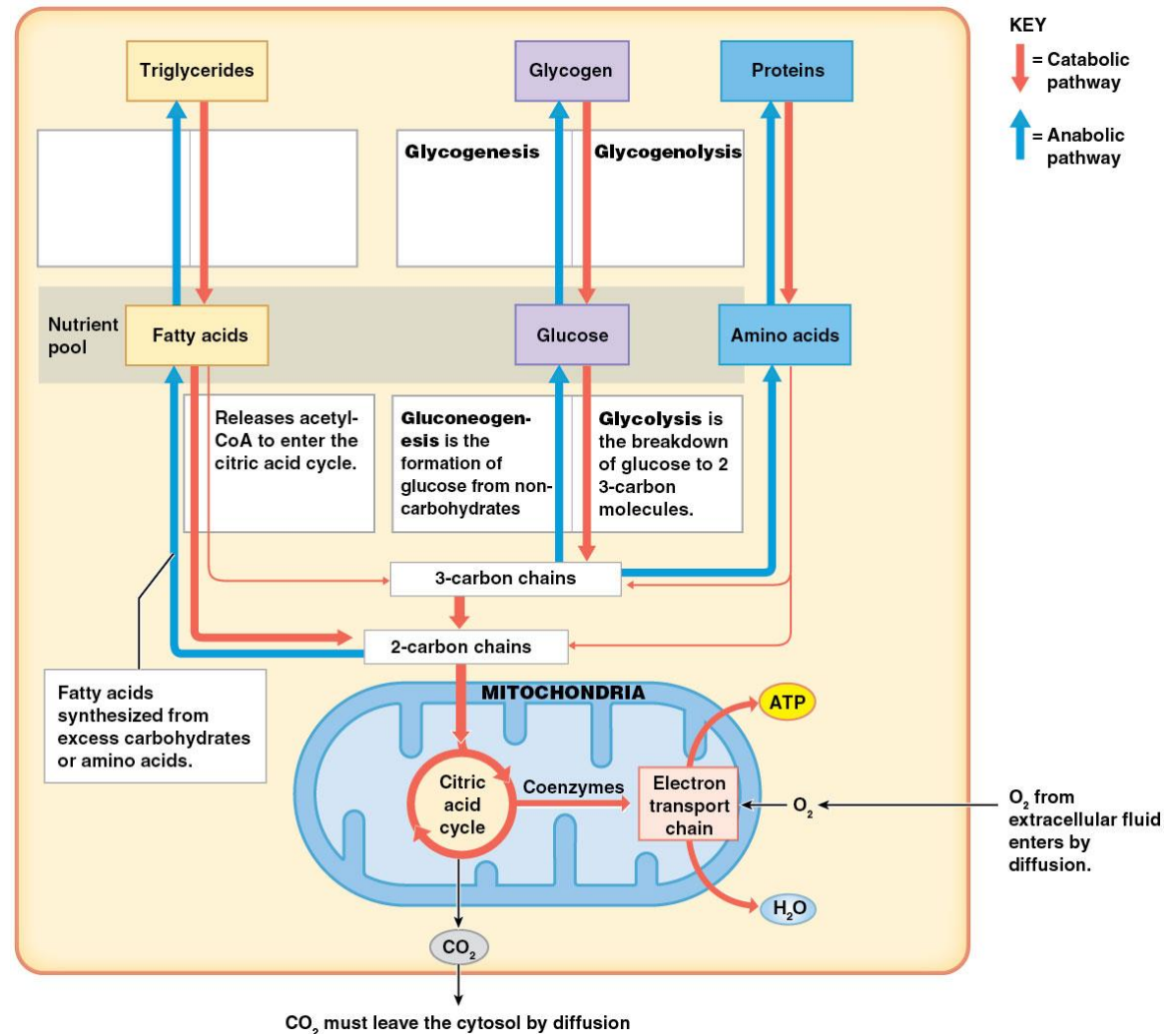
Module 23.7: Nutrient metabolism pathways

- **Glycogenesis**—formation of glycogen from glucose
- **Glycogenolysis**—breakdown of glycogen into glucose
- **Gluconeogenesis**—formation of glucose from noncarbohydrates
- **Glycolysis**—breakdown of glucose to two 3-carbon molecules



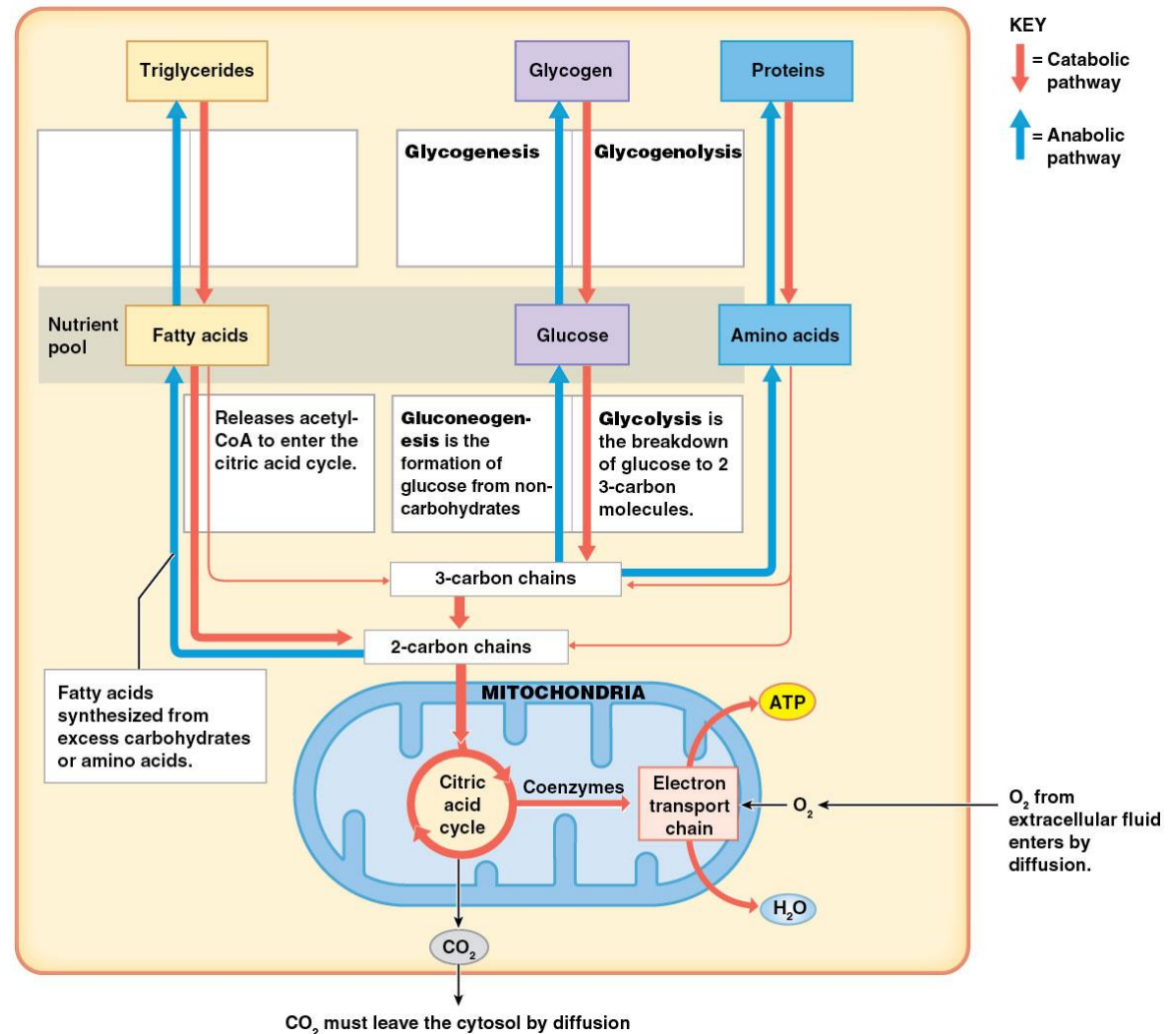
Module 23.7: Nutrient metabolism pathways

- Amino acids are used for protein synthesis
- In starvation, muscle proteins are mobilized



Module 23.7: Nutrient metabolism pathways

- CO_2 leaves cytosol by diffusion
- O_2 is delivered by diffusion
- Both require respiratory function



Module 23.7: Review

- A. Compare glycogenesis and glycogenolysis.
- B. Why do cells make new compounds?

Learning Outcome: Define glycogenesis, glycogenolysis, and gluconeogenesis.

Section 2: Digestion and Metabolism of Organic Nutrients

Learning Outcomes

- 23.8 Outline the steps involved in digestion, and list the nutrients used by the body.
- 23.9 Describe carbohydrate metabolism.
- 23.10 Describe the mechanisms of lipid transport and distribution.
- 23.11 Describe the fate of fatty acids in lipid metabolism.

Section 2: Digestion and Metabolism of Organic Nutrients

Learning Outcomes (continued)

- 23.12 Summarize the main features of protein metabolism and the use of proteins as an energy source.
- 23.13 Differentiate between the absorptive and postabsorptive metabolic states, and summarize the characteristics of each.
- 23.14 Explain the role of fat-soluble vitamins and water-soluble vitamins in metabolic pathways.

Section 2: Digestion and Metabolism of Organic Nutrients

Learning Outcomes (continued)

23.15 Explain what constitutes a balanced diet and why such a diet is important.

23.16 **Clinical Module:** Describe several metabolic disorders resulting from nutritional or biochemical problems.

Module 23.8: Digestion involves a series of steps to make nutrients available to the body

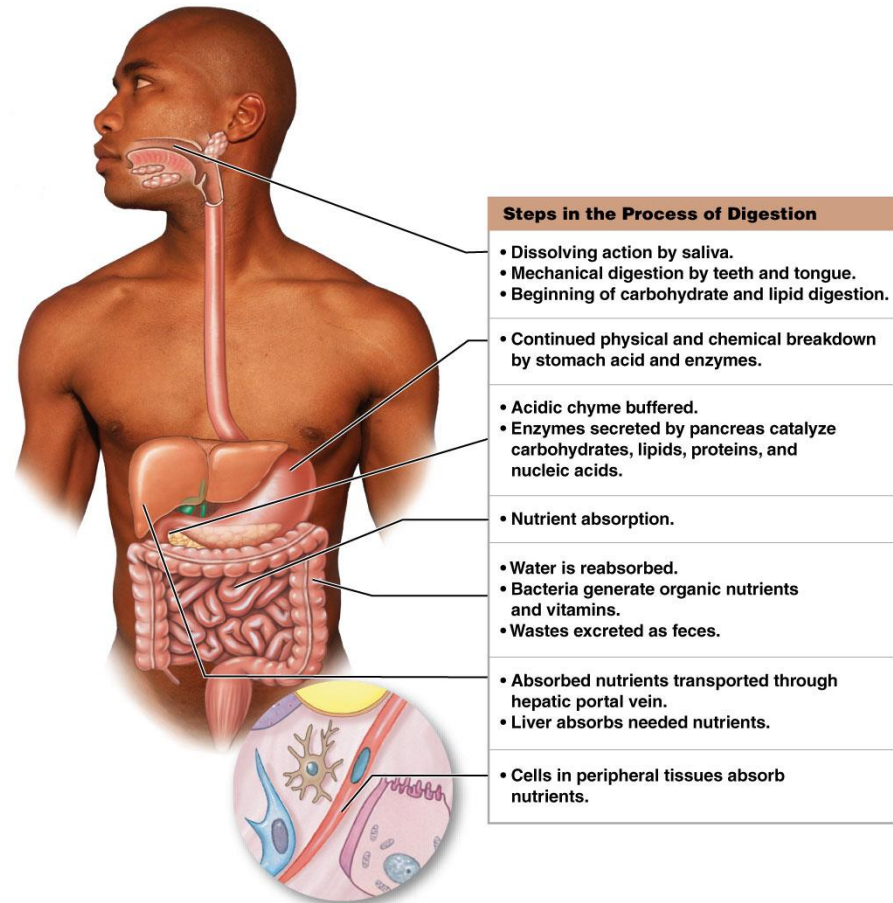
Digestion

- Breakdown of the physical structure and chemical bonds of organic compounds
- Resulting compounds are absorbed in the digestive tract and distributed through the bloodstream
- Cells throughout the body utilize these organic molecules for energy and to restock the intracellular nutrient pool

Module 23.8: Review of digestion

Oral cavity

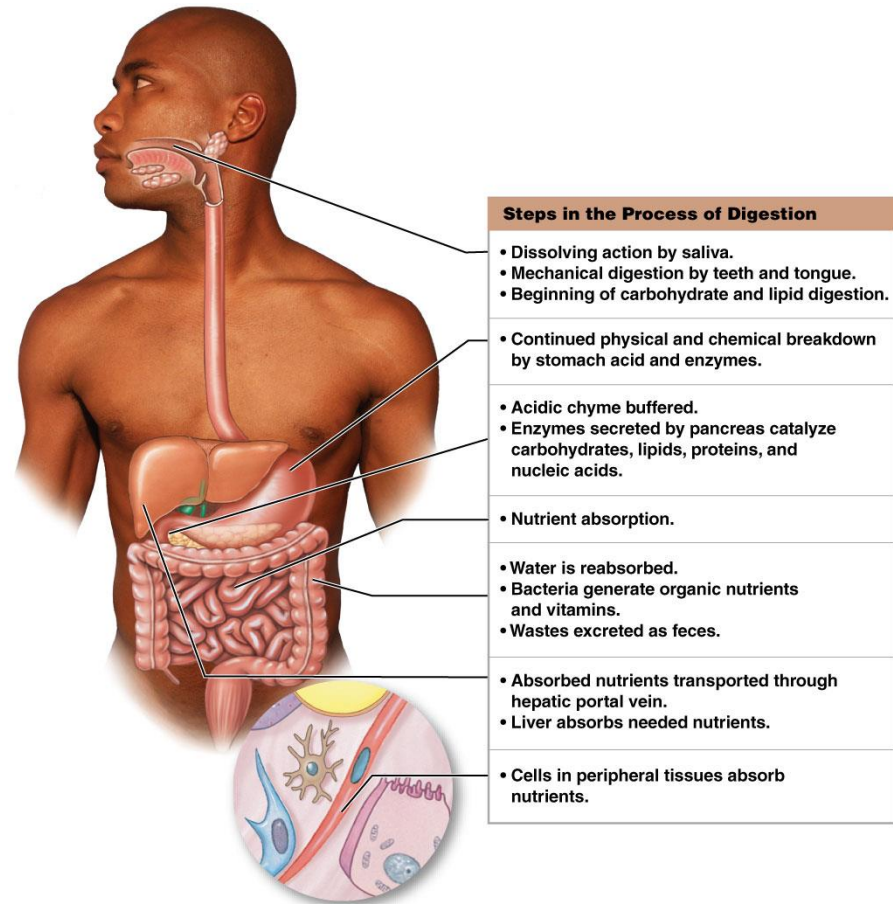
- Saliva dissolves some organic molecules
- Mechanical processing by teeth and tongue disrupts physical structures (provides access for digestive enzymes)
- Chemical digestion of complex carbohydrates and lipids



Module 23.8: Review of digestion

Stomach

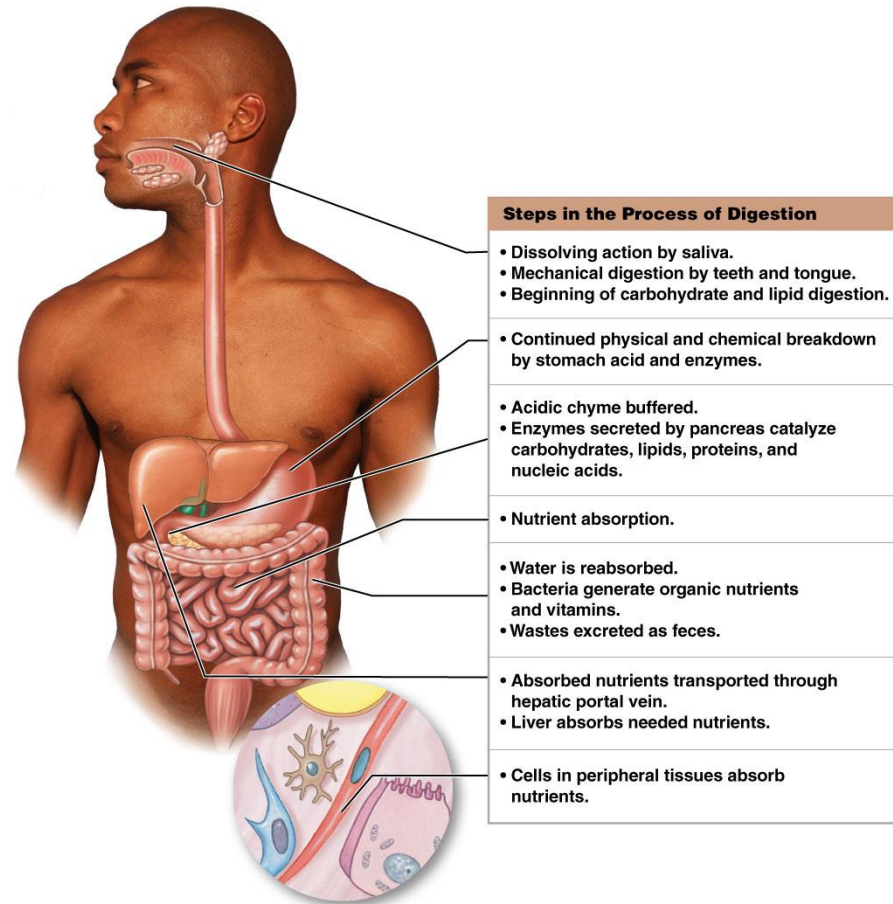
- Material further broken down physically and chemically by stomach acid and enzymes
- Protein digestion begins



Module 23.8: Review of digestion

Duodenum

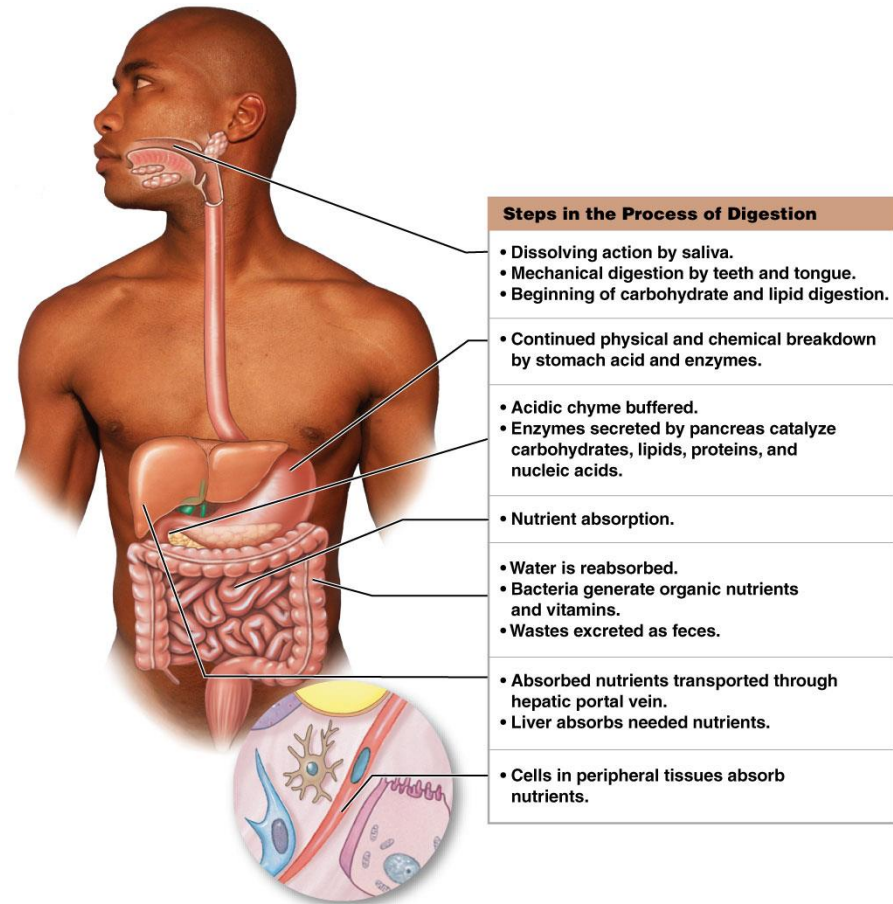
- Buffers from the pancreas and liver moderate the pH of the arriving chyme
- Digestive enzymes catalyze catabolism of all organic molecules needed by cells



Module 23.8: Review of digestion

Jejunum and ileum

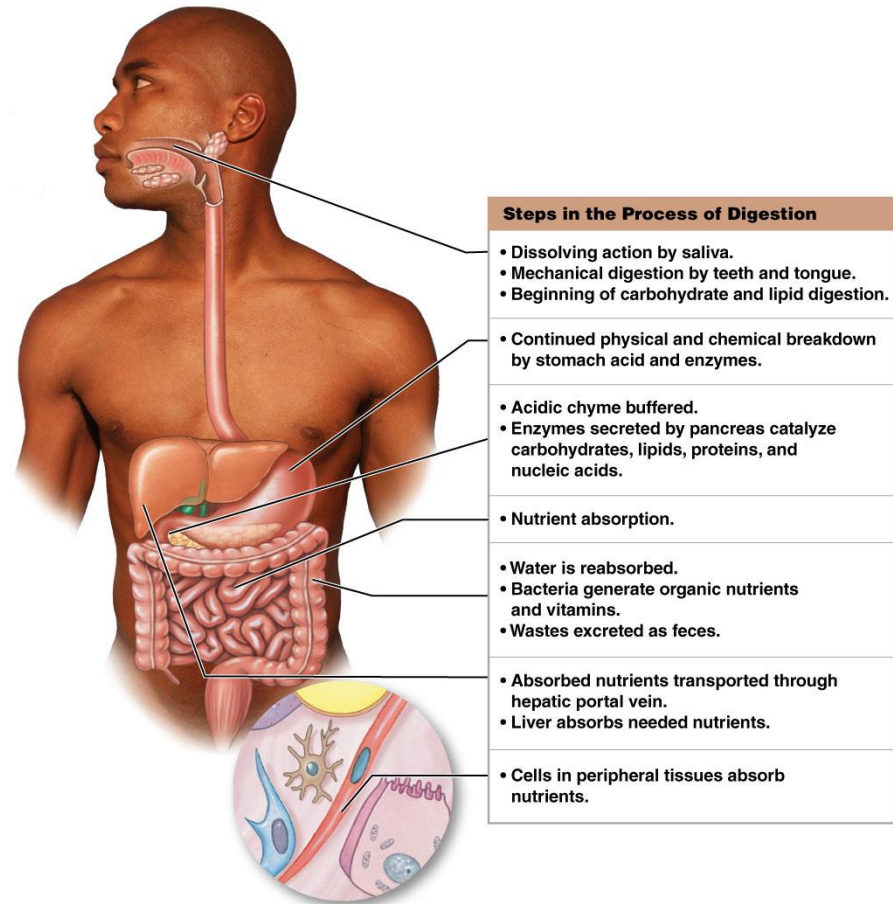
- Most nutrient absorption occurs here
- Nutrients delivered to the liver by the hepatic portal vein, where they are absorbed as needed



Module 23.8: Review of digestion

Large intestine

- Water reabsorbed
- Bacterial action generates organic nutrients and vitamins
- Indigestible material and wastes are excreted as feces



Module 23.8: Review

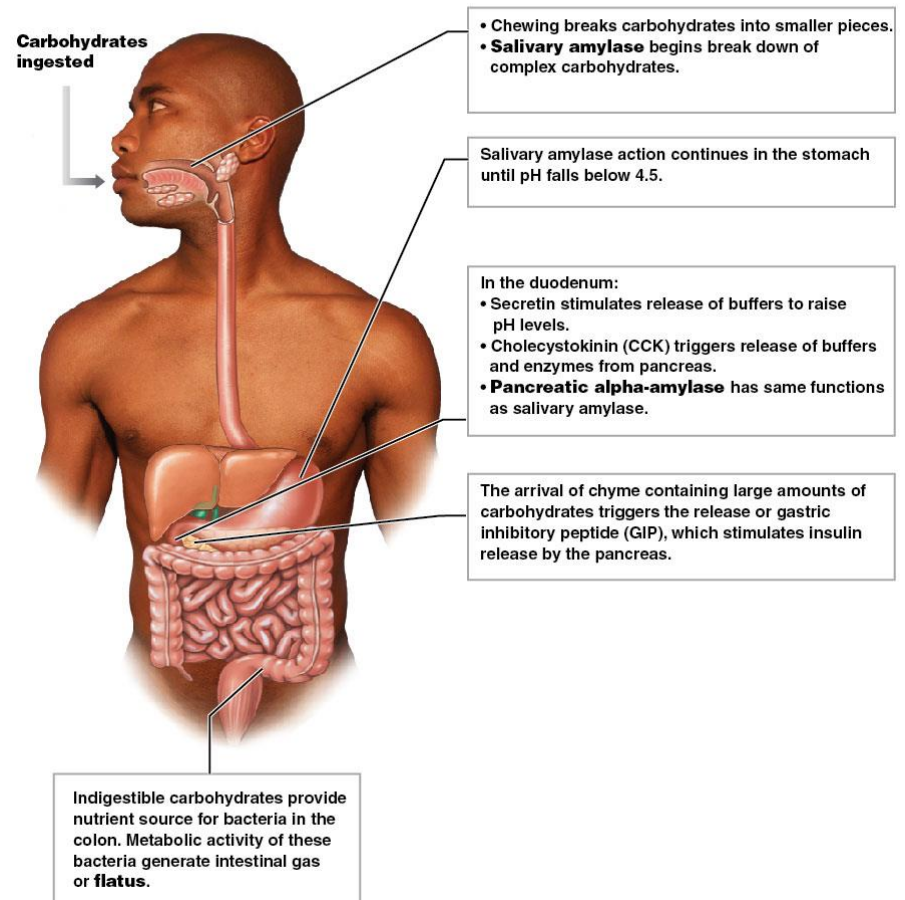
- A. Why is digestion important?
- B. Where does most nutrient absorption occur?
- C. Most of the absorbed nutrients enter into which blood vessel?

Learning Outcome: Outline the steps involved in digestion, and list the nutrients used by the body.

Module 23.9: Carbohydrates are usually the preferred substrates for catabolism and ATP production under resting conditions

Steps of carbohydrate digestion

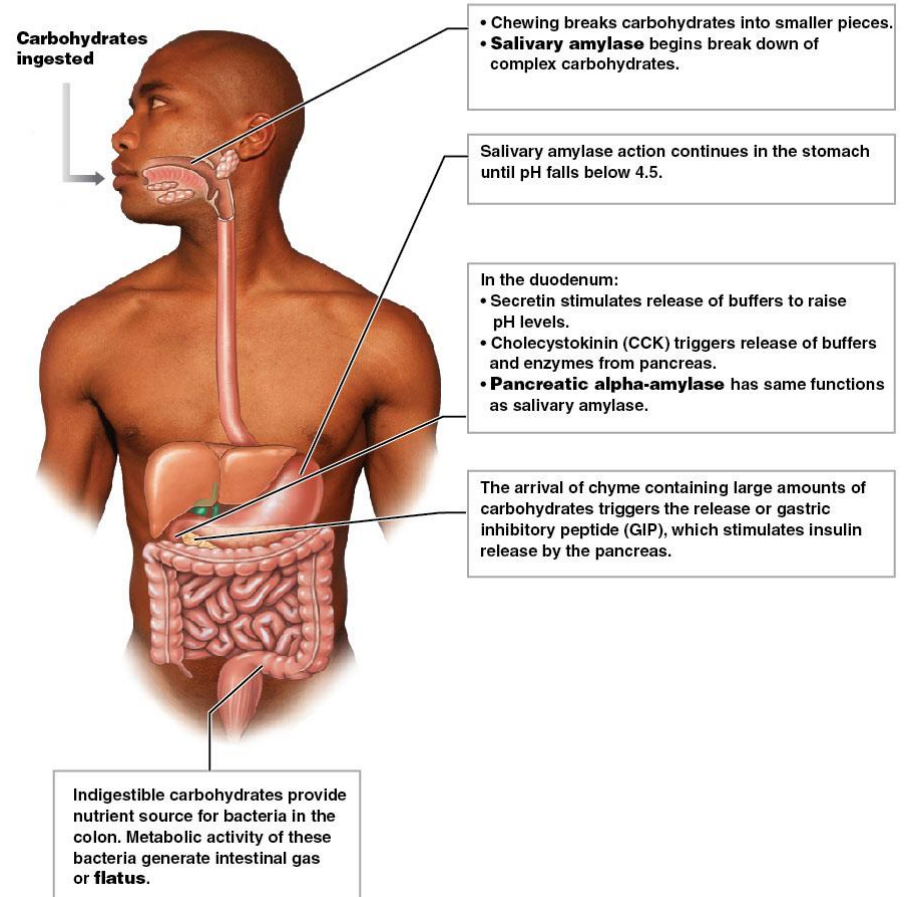
- Begins in the mouth
 - Chewing mechanically breaks apart the bolus and mixes with saliva
 - **Salivary amylase** breaks down complex carbohydrates into disaccharides and trisaccharides



Module 23.9: Carbohydrates

Steps of carbohydrate digestion (continued)

- Amylase is deactivated by the acidity in the stomach
- Active for about 1–2 hours, until pH falls below 4.5

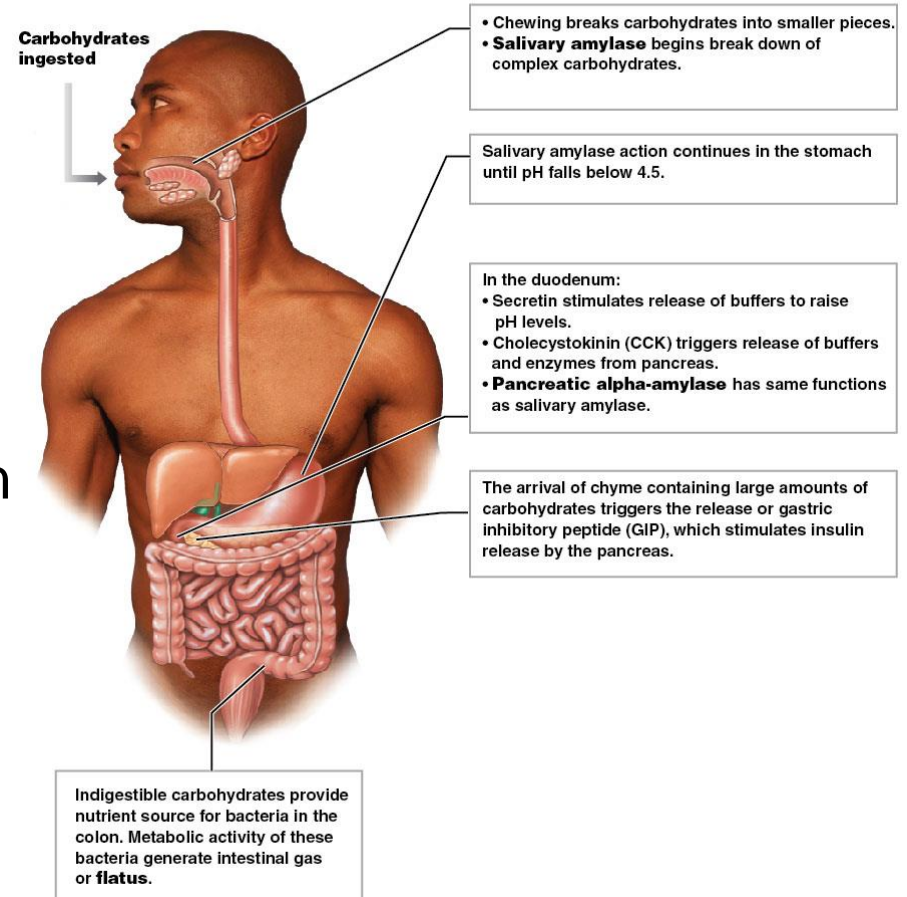


Module 23.9: Carbohydrates

Steps of carbohydrate digestion (continued)

■ Chyme arrives in the duodenum

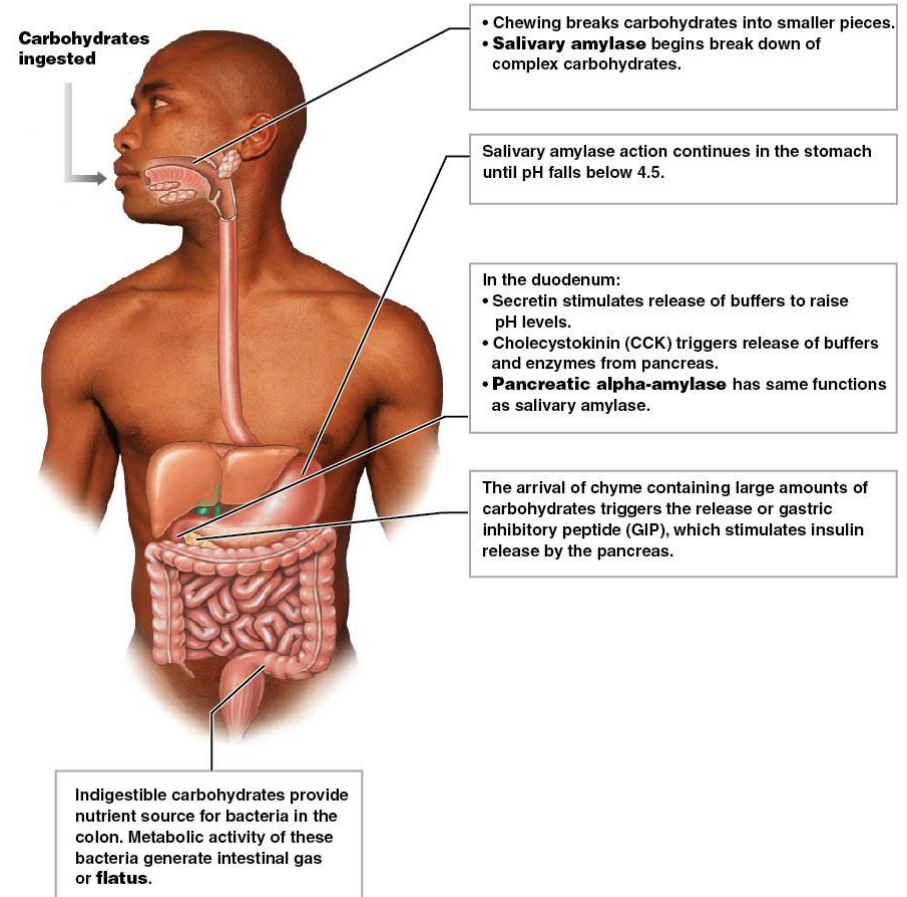
- Secretin signals buffer release
- CCK triggers release of pancreatic enzymes
 - **Pancreatic alpha-amylase** continues carbohydrate digestion



Module 23.9: Carbohydrates

Steps of carbohydrate digestion (continued)

- Arrival of chyme with carbohydrates triggers release of gastric inhibitory protein (GIP)
 - Stimulates insulin release

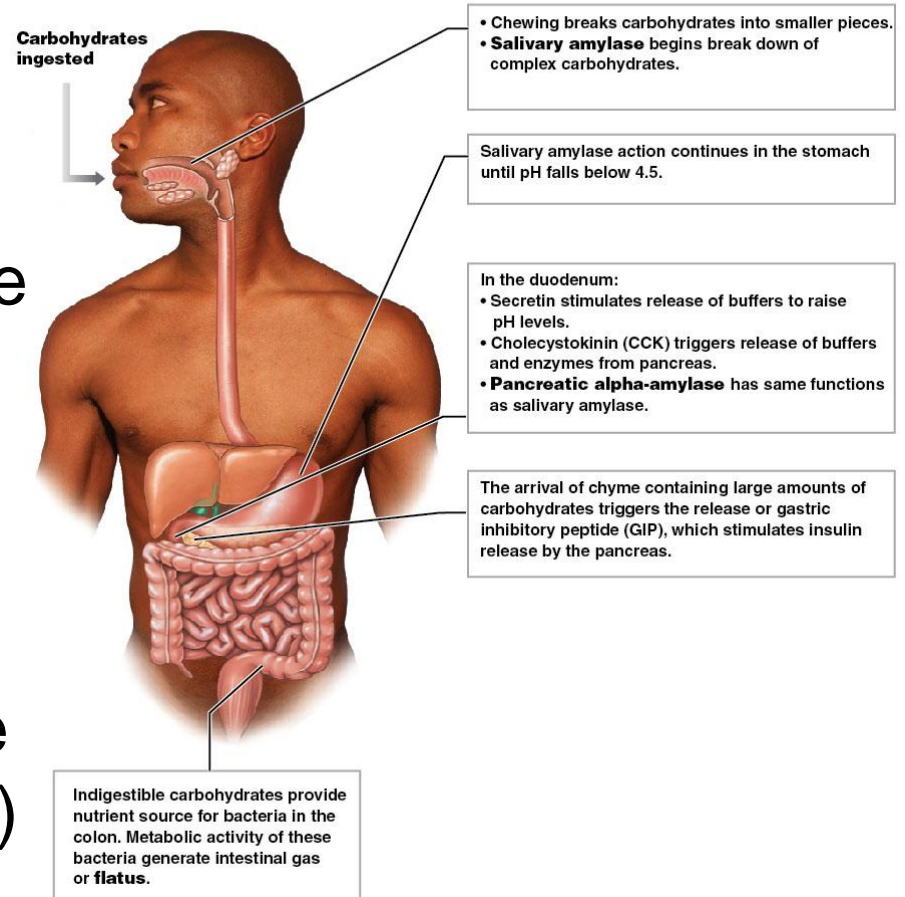


Module 23.9: Carbohydrates

Steps of carbohydrate digestion (continued)

In the jejunum, brush border enzymes finish carbohydrate digestion down to simple sugars (monosaccharides)

- **Maltase** (digests maltose into glucose + glucose)
- **Sucrase** (digests sucrose into glucose + fructose)
- **Lactase** (digests lactose into glucose + galactose)

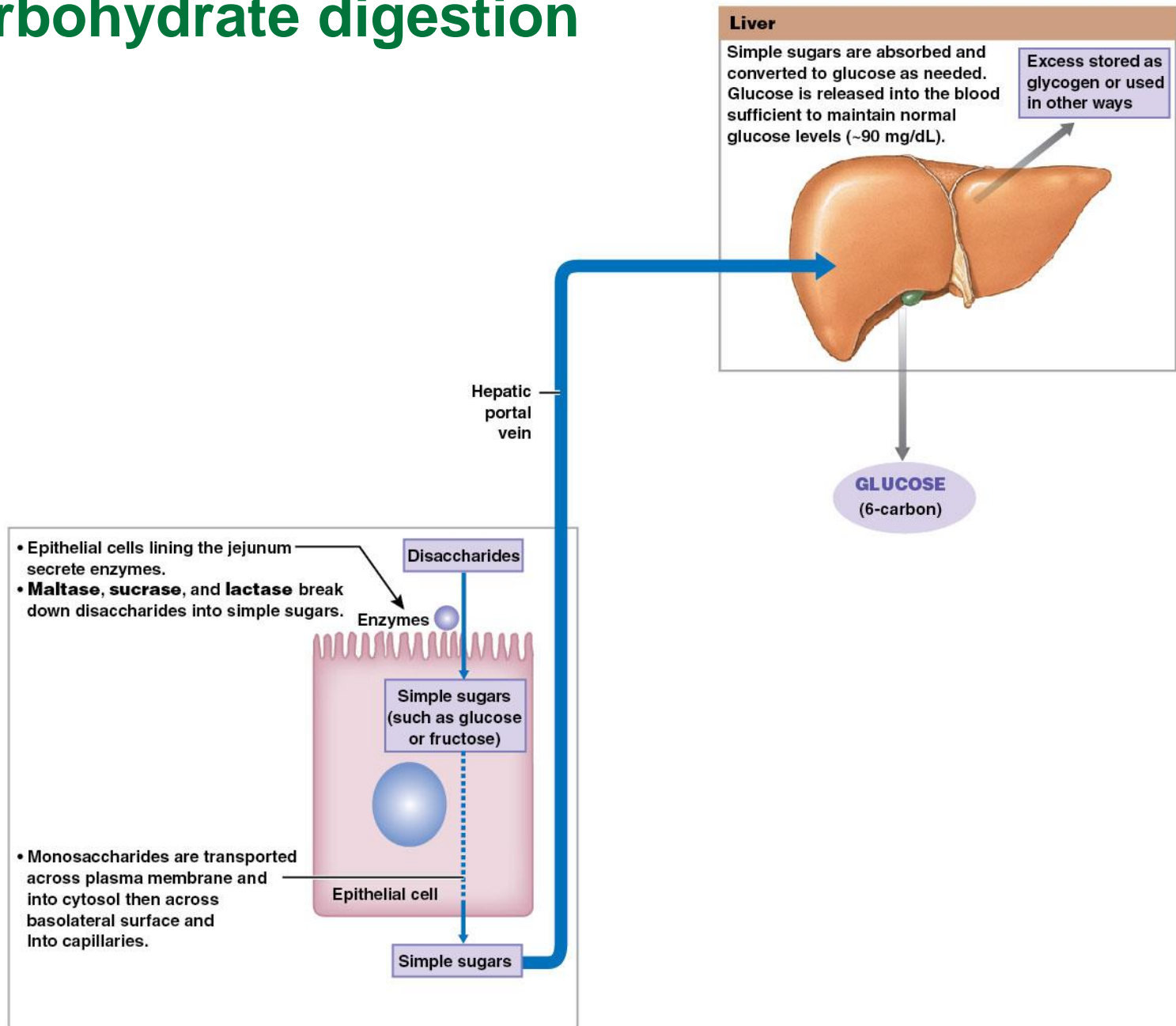


Module 23.9: Carbohydrates

Carbohydrate absorption and transport

- Simple sugars are transported across the small intestine epithelial cells
 - Leave cells by facilitated diffusion through basolateral surface
- Diffuse into capillaries
- Transported to the liver by the hepatic portal vein
- Released into blood to maintain normal glucose levels (~90 mg/dL)
- Liver converts excess glucose to glycogen

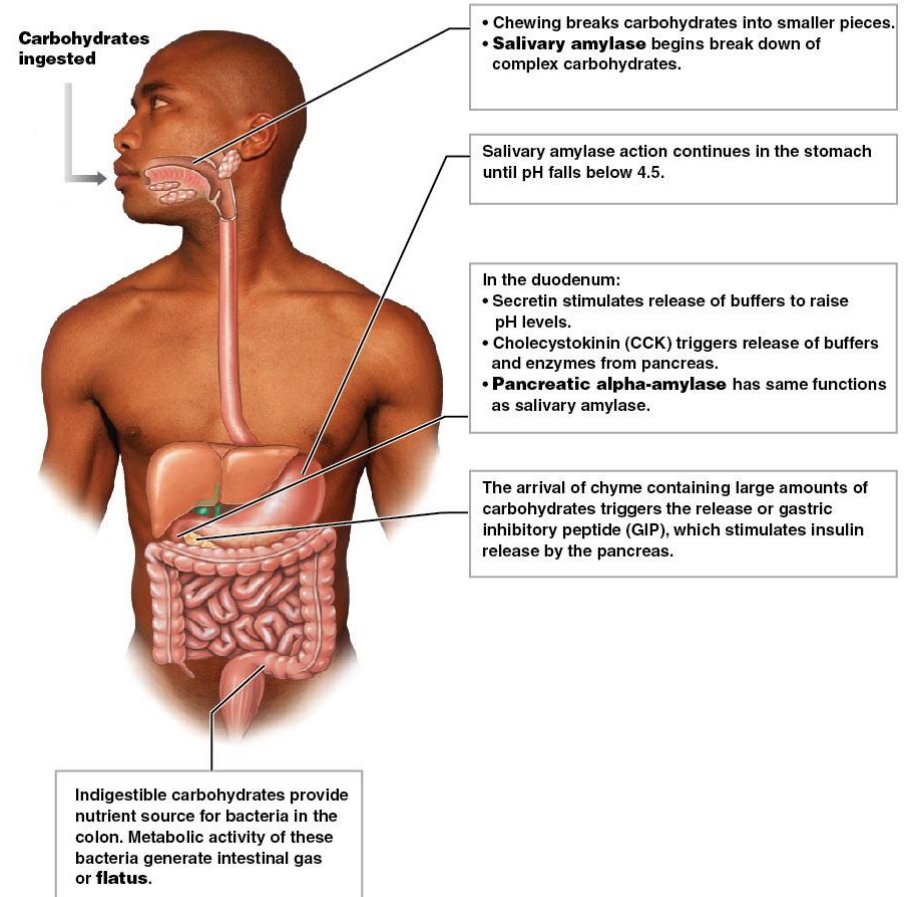
Carbohydrate digestion



Module 23.9: Carbohydrates

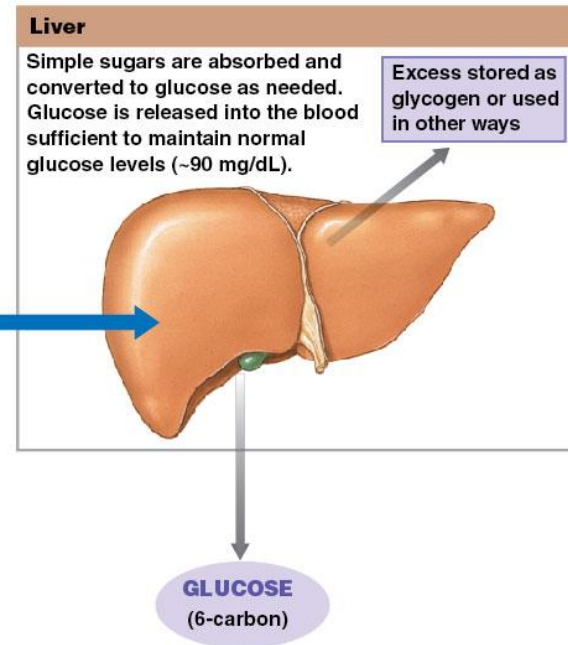
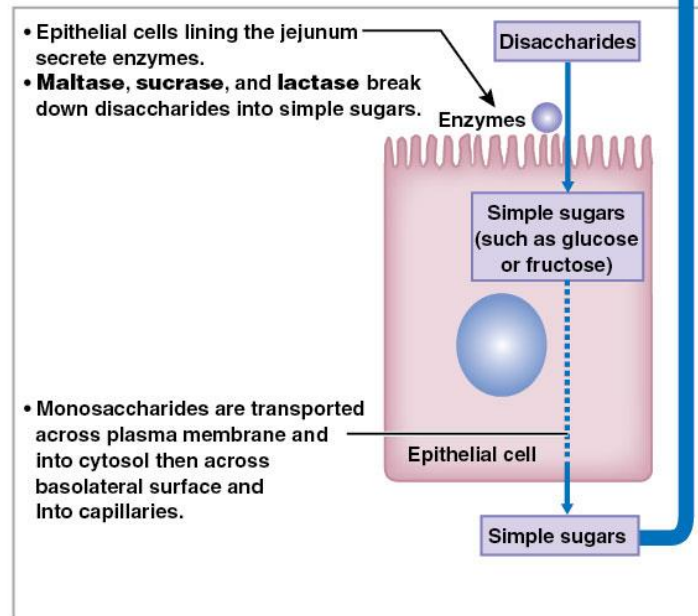
Steps of carbohydrate digestion (continued)

- In the large intestine, remaining indigestible carbohydrates (such as cellulose) provide nutrient source for bacteria in the colon
 - Bacterial metabolic activity generates intestinal gas (**flatus**)



Module 23.9: Carbohydrates

- Simple sugars are absorbed and converted to glucose as needed
- Excess sugar is stored as glycogen

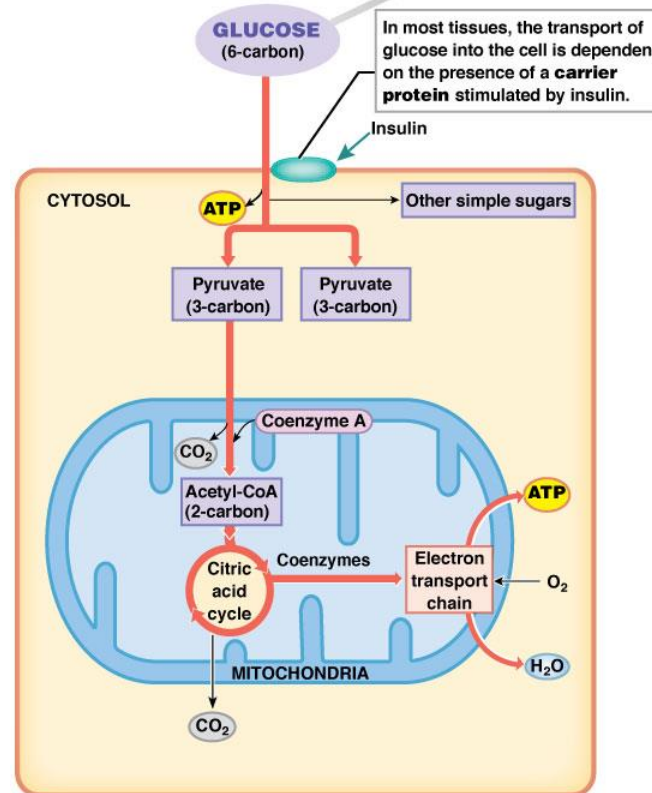
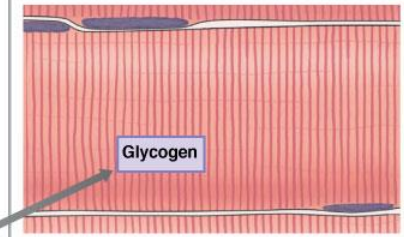


Module 23.9: Carbohydrates

- Resting skeletal muscle breaks down fatty acids for energy and absorbs glucose to build glycogen reserves

Skeletal Muscle

Resting skeletal muscles primarily break down fatty acids for energy and absorb glucose to build up their glycogen reserves.



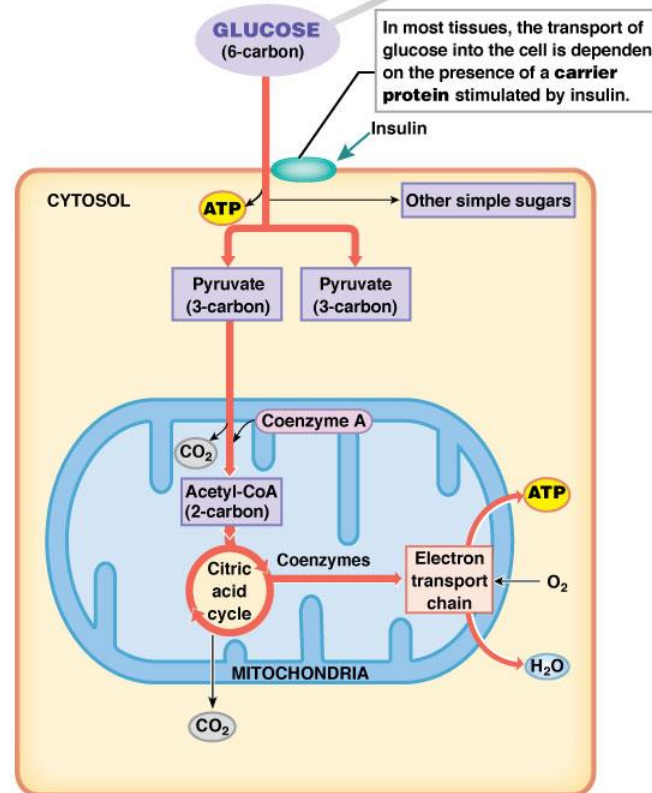
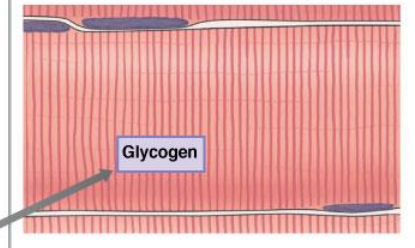
Module 23.9: Carbohydrates

In most tissues, glucose is transported into cell by **carrier protein** (regulated by insulin)

- May be converted to ribose or glycerol

Skeletal Muscle

Resting skeletal muscles primarily break down fatty acids for energy and absorb glucose to build up their glycogen reserves.

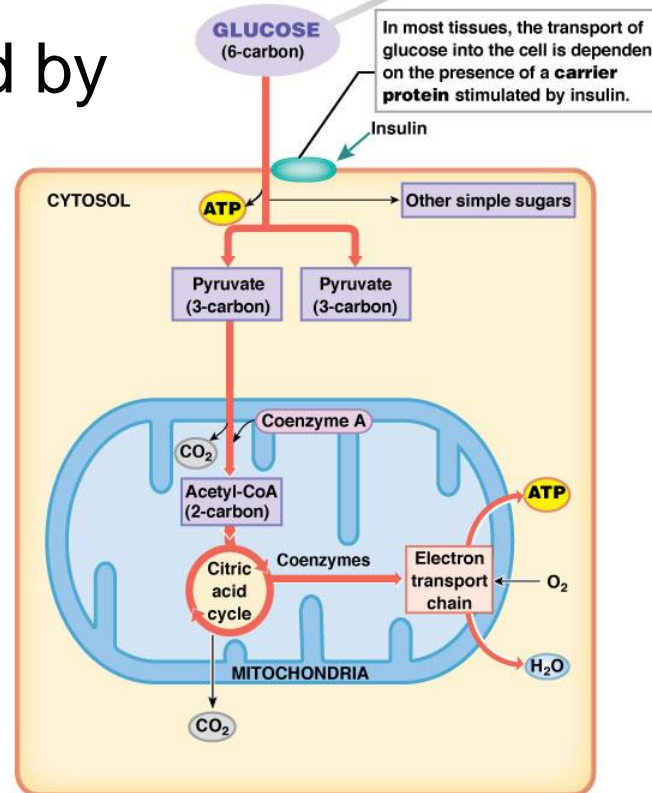
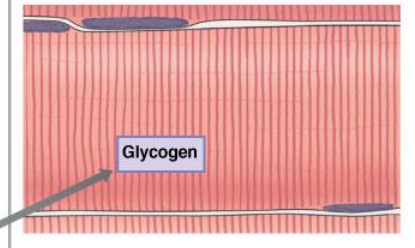


Module 23.9: Carbohydrates

- If needed for energy, glucose is converted to 2 **pyruvate** molecules in glycolysis
 - Produces 2 ATP for every glucose molecule
- Pyruvates are used by mitochondria
 - For each pair of pyruvates, cell uses 6 O₂ and generates 6 CO₂, 12 H₂O, 30–32 ATP

Skeletal Muscle

Resting skeletal muscles primarily break down fatty acids for energy and absorb glucose to build up their glycogen reserves.



Module 23.9: Review

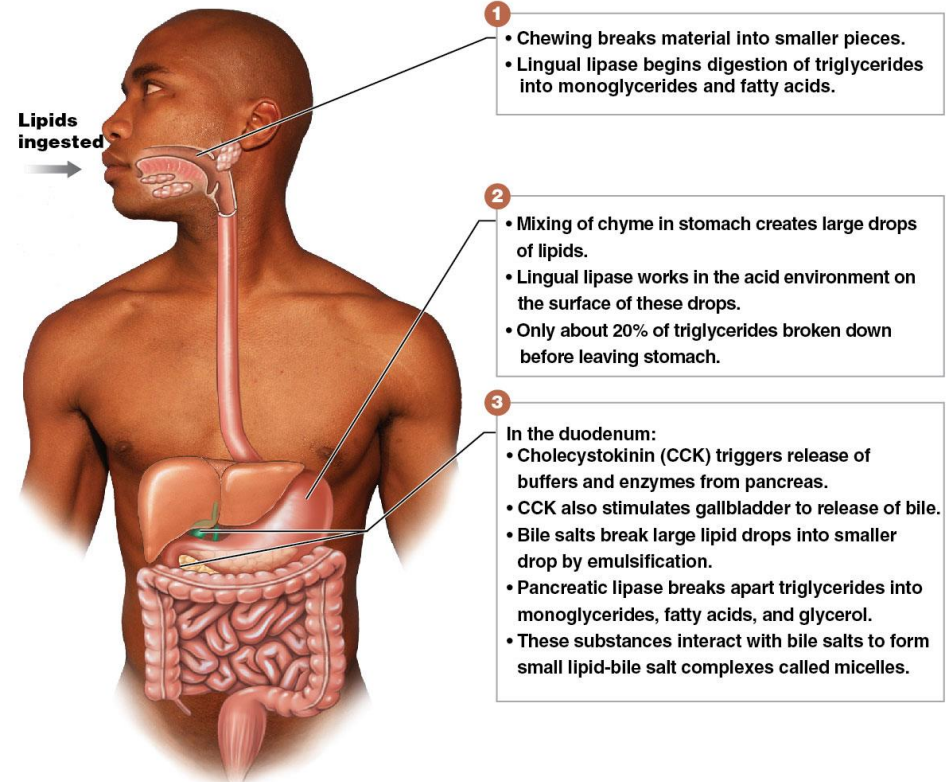
- A. Describe the source of intestinal gas.
- B. Explain the role of glycogen in cellular metabolism.
- C. Explain why carbohydrates are preferred over proteins and lipids as an energy source.

Learning Outcome: Describe carbohydrate metabolism.

Module 23.10: Lipids reach the bloodstream in chylomicrons; the cholesterol is then extracted and released as lipoproteins

Lipid digestion

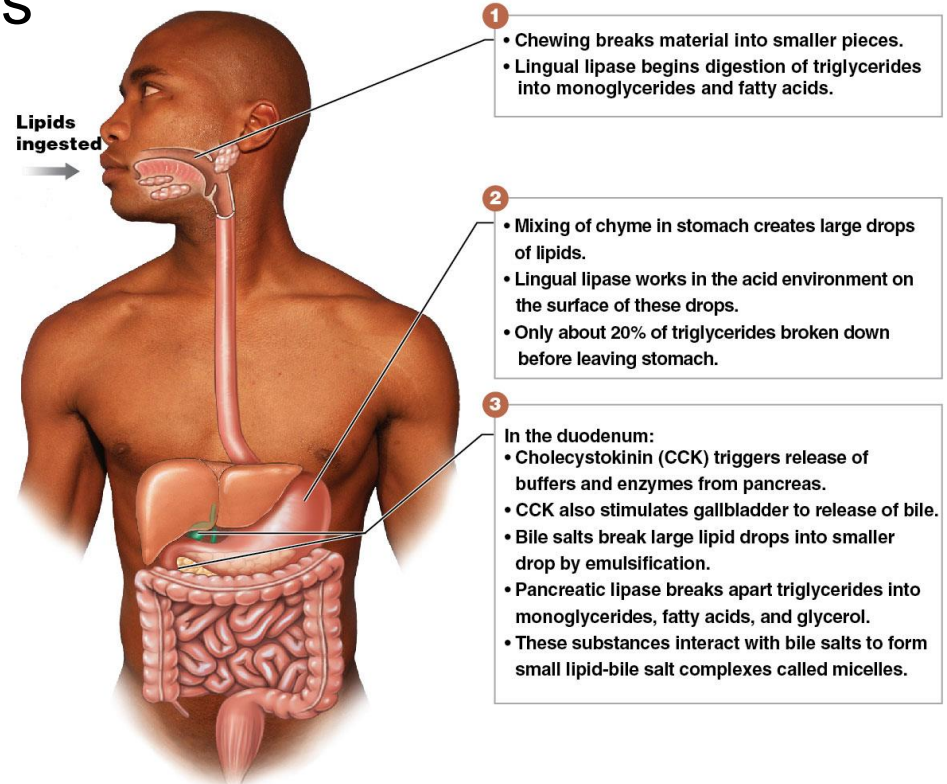
- Begins in the mouth
 - Mechanical breakdown into smaller chunks
 - **Lingual lipase** breaks down triglycerides into monoglycerides and fatty acids



Module 23.10: Lipids

Lipid digestion (continued)

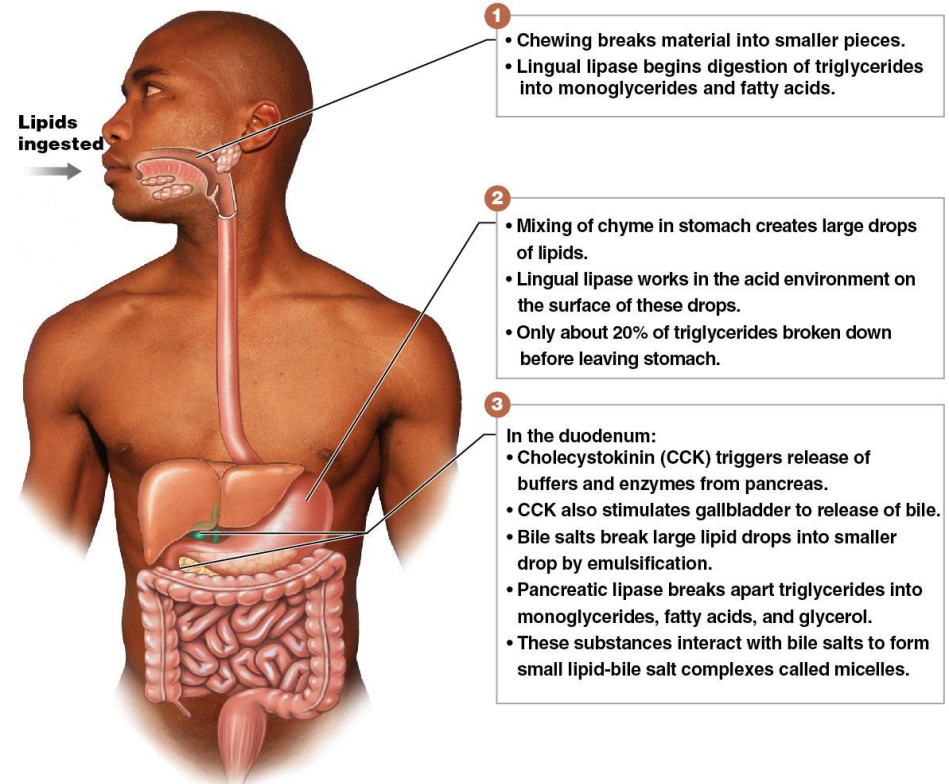
- Continues in the stomach
 - Mixing of chyme in the stomach creates large drops containing a variety of lipids
 - Lingual lipase continues to function
 - Only about 20 percent of triglycerides are broken down by the time chyme leaves the stomach



Module 23.10: Lipids

Lipid digestion (continued)

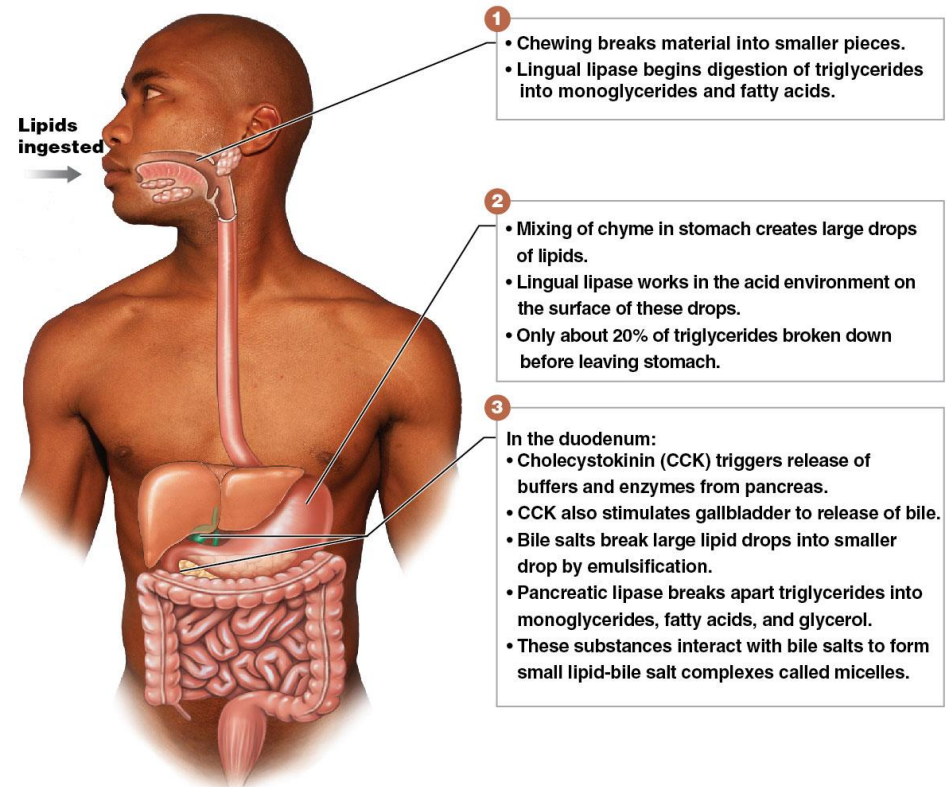
- Completes in the duodenum
 - Release of CCK triggers contraction of gallbladder
 - Ejects bile into the duodenum
 - **Bile salts** break up lipid drops into smaller droplets in a process called **emulsification**



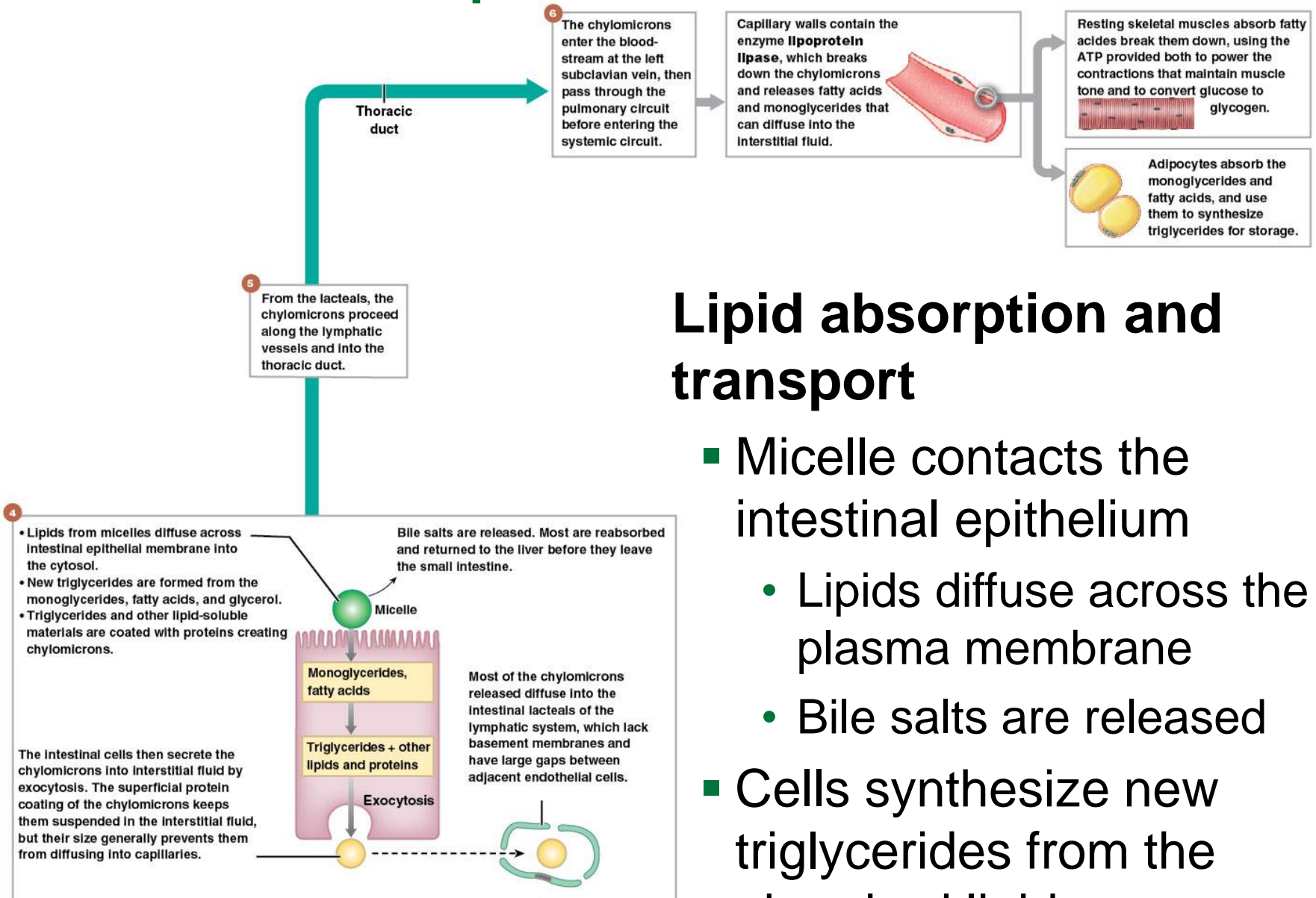
Module 23.10: Lipids

Lipid digestion (continued)

- Completes in the duodenum (continued)
 - CCK stimulates secretion of pancreatic enzymes
 - **Pancreatic lipase** breaks apart triglycerides to form mixture of fatty acids, monoglycerides, and glycerol
 - Released molecules form **micelles** (lipid–bile salt complexes)



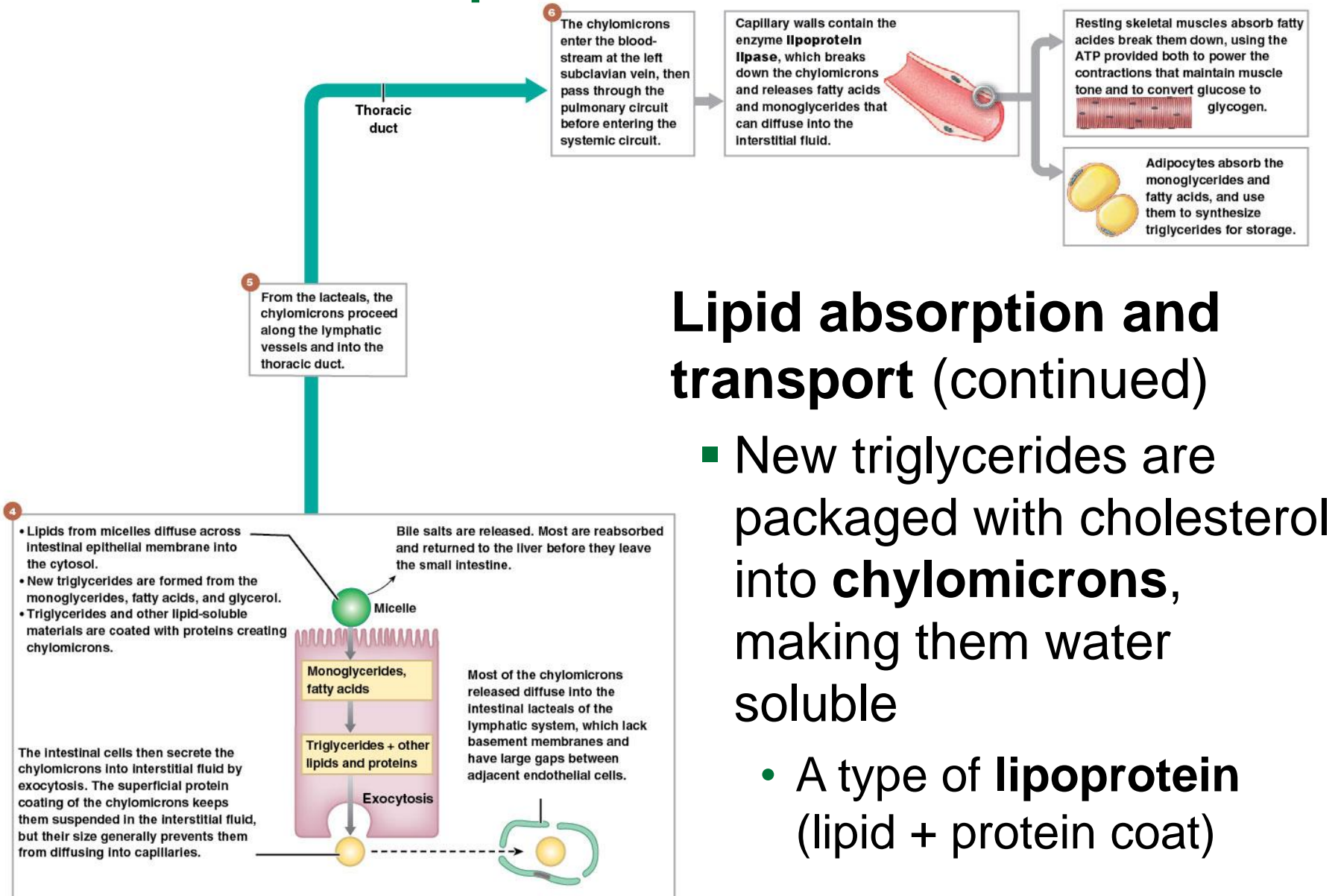
Module 23.10: Lipids



Lipid absorption and transport

- Micelle contacts the intestinal epithelium
 - Lipids diffuse across the plasma membrane
 - Bile salts are released
- Cells synthesize new triglycerides from the absorbed lipids

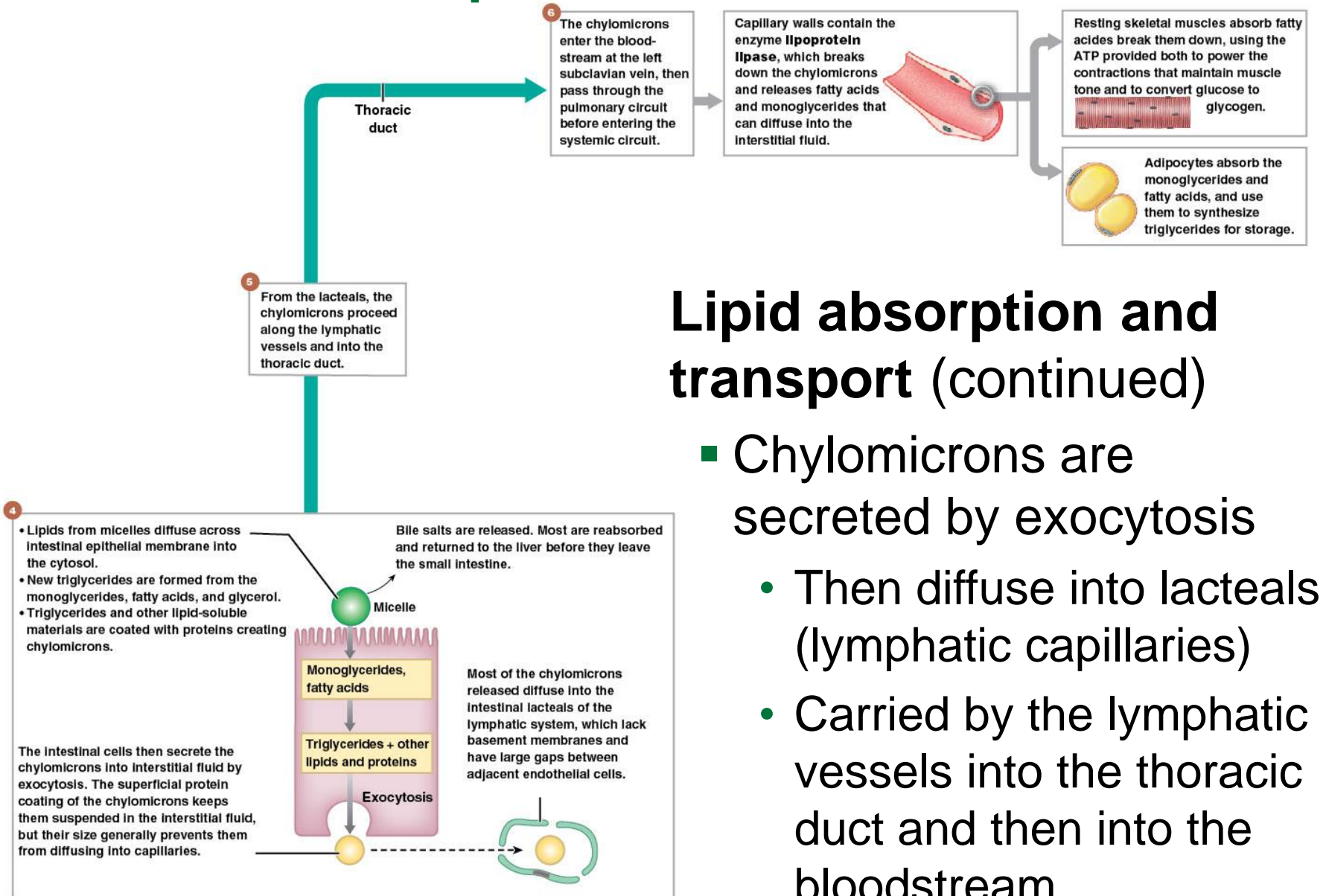
Module 23.10: Lipids



Lipid absorption and transport (continued)

- New triglycerides are packaged with cholesterol into **chylomicrons**, making them water soluble
- A type of **lipoprotein** (lipid + protein coat)

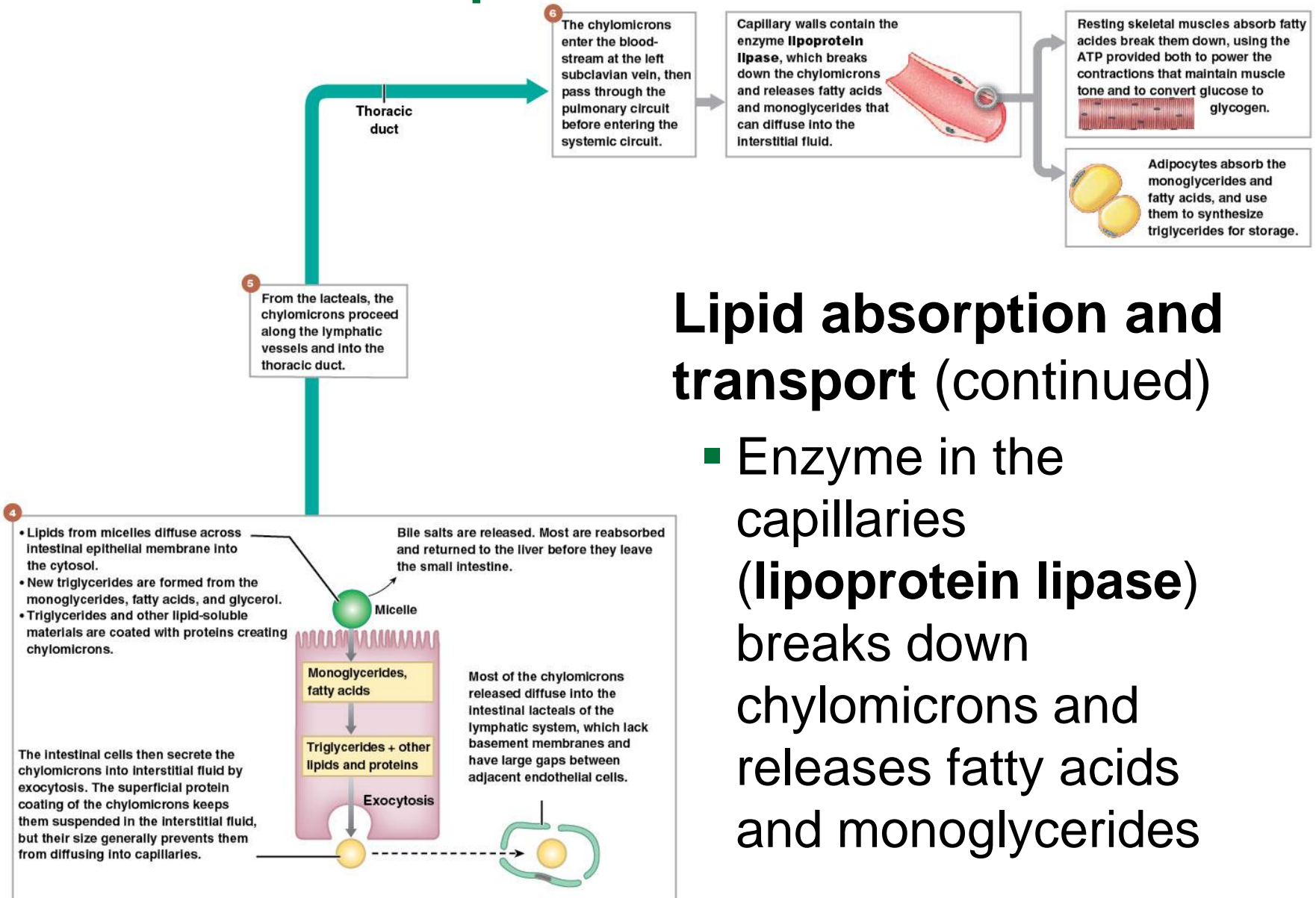
Module 23.10: Lipids



Lipid absorption and transport (continued)

- Chylomicrons are secreted by exocytosis
 - Then diffuse into lacteals (lymphatic capillaries)
 - Carried by the lymphatic vessels into the thoracic duct and then into the bloodstream

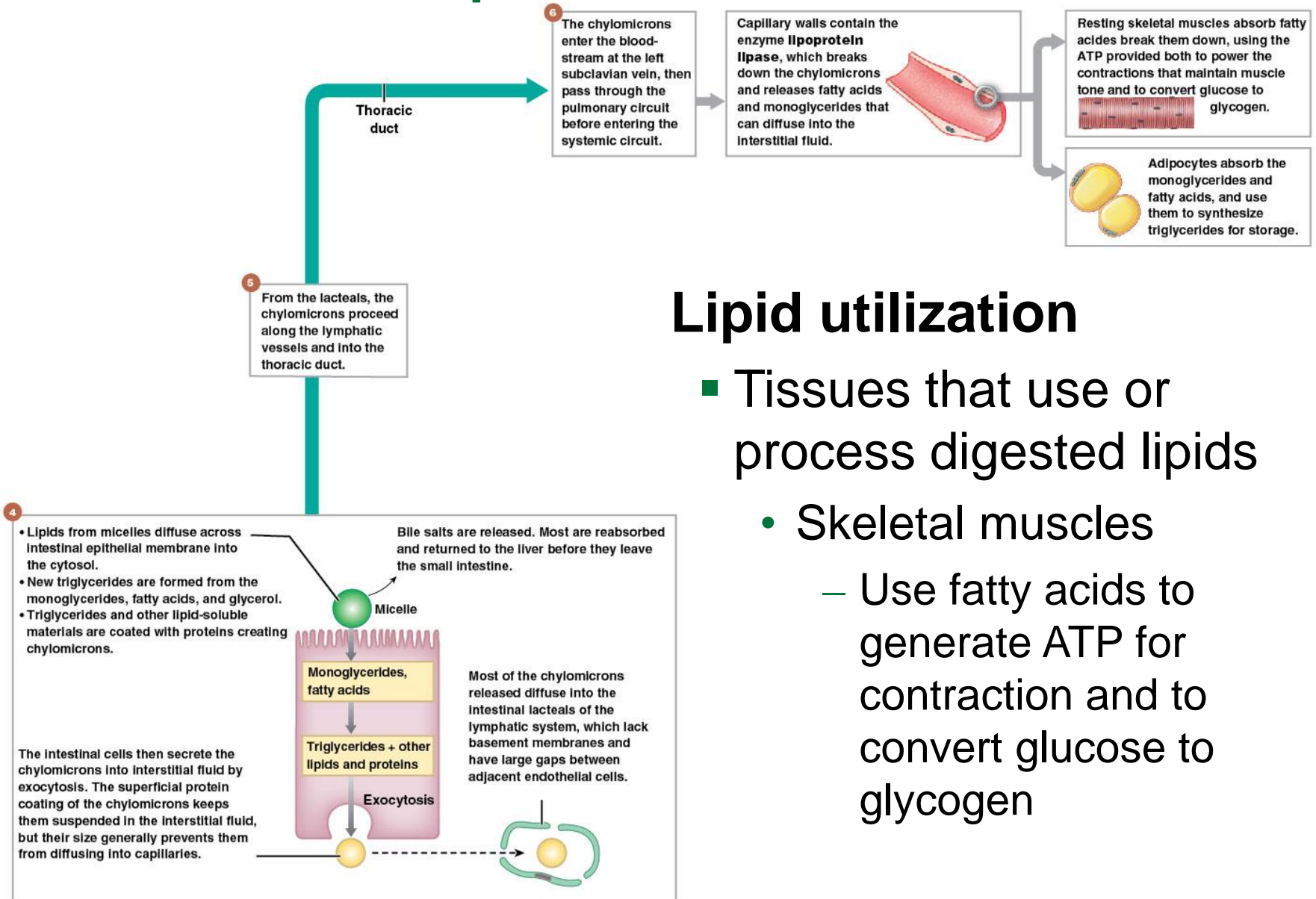
Module 23.10: Lipids



Lipid absorption and transport (continued)

- Enzyme in the capillaries (**lipoprotein lipase**) breaks down chylomicrons and releases fatty acids and monoglycerides

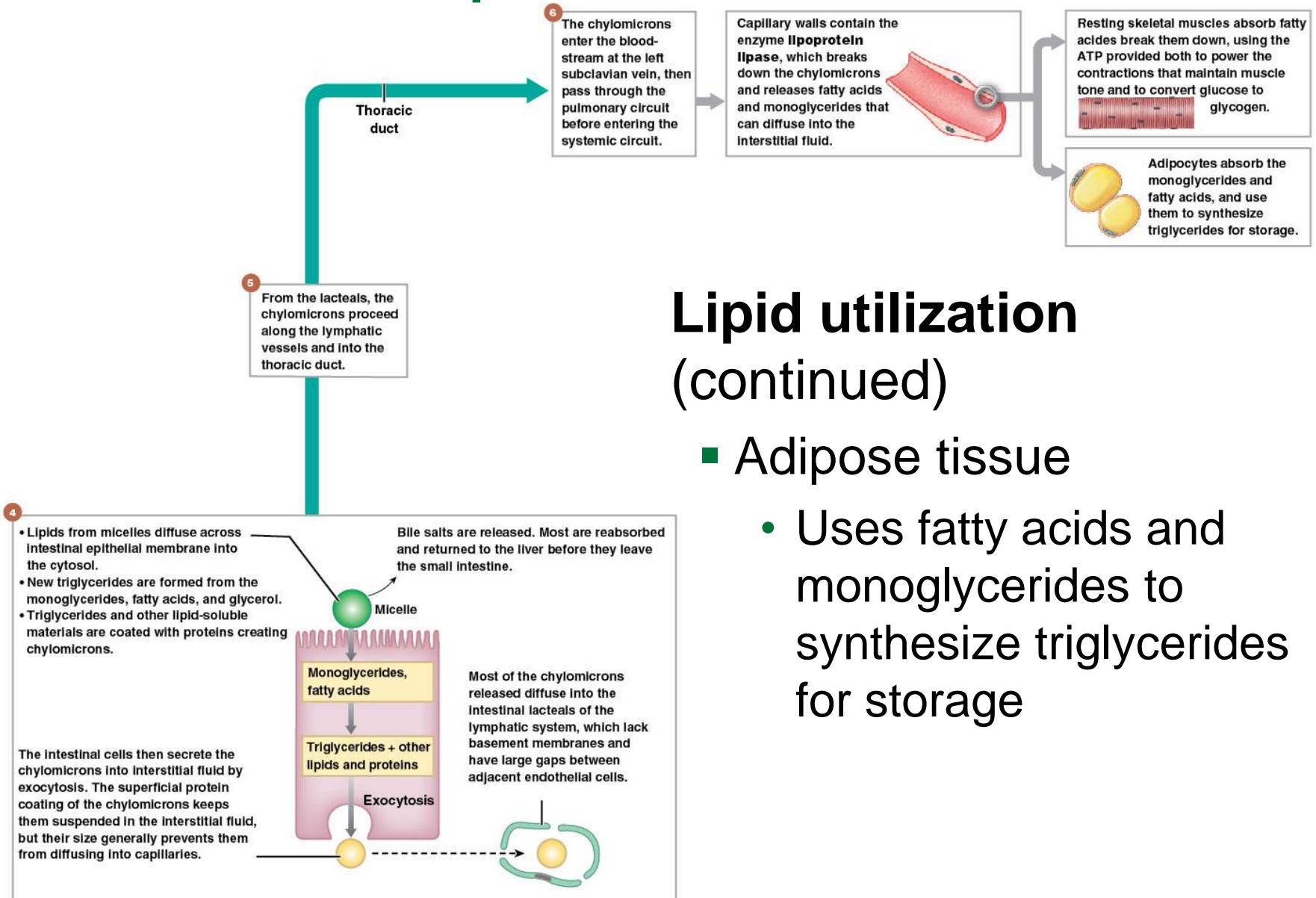
Module 23.10: Lipids



Lipid utilization

- Tissues that use or process digested lipids
 - Skeletal muscles
 - Use fatty acids to generate ATP for contraction and to convert glucose to glycogen

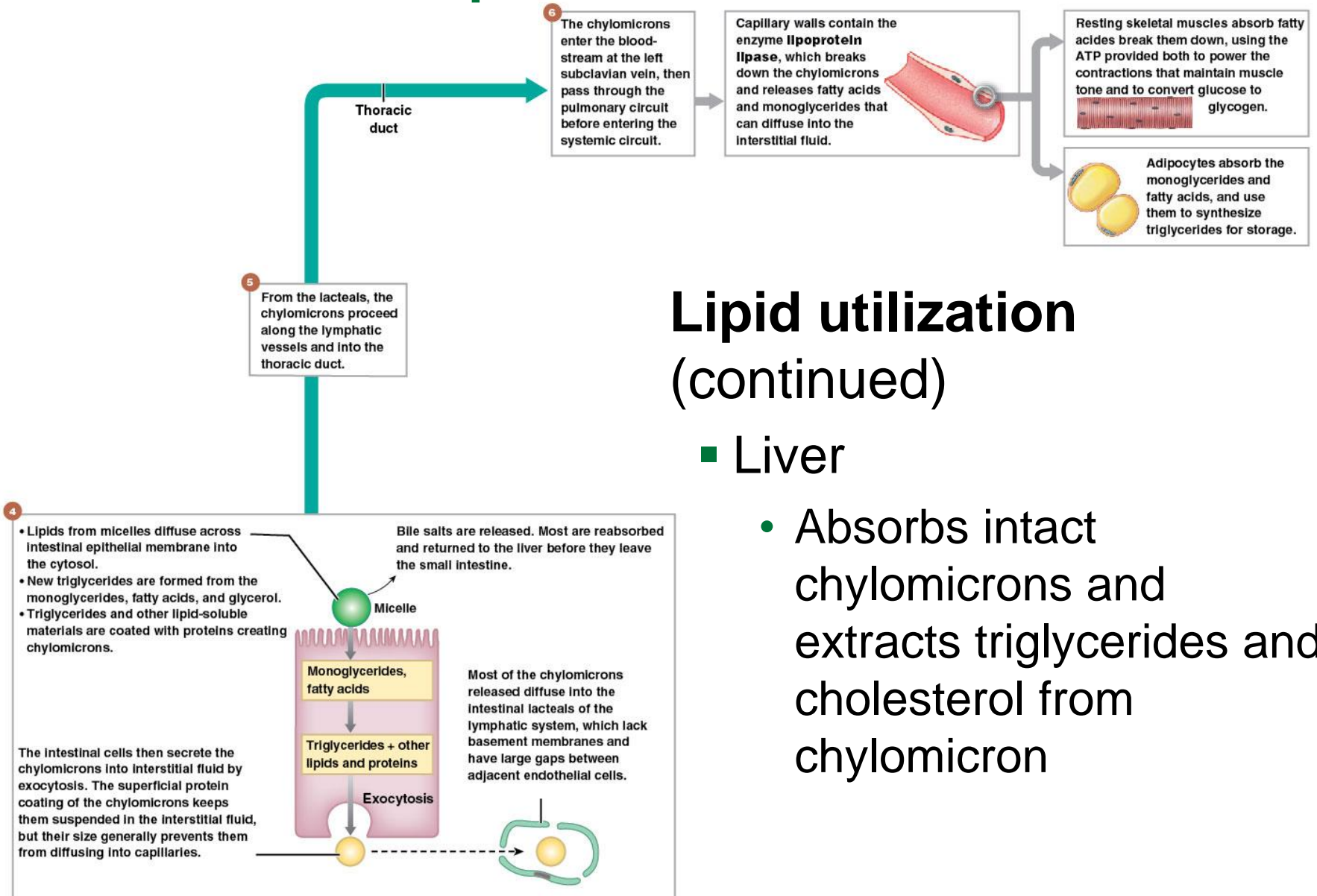
Module 23.10: Lipids



Lipid utilization (continued)

- Adipose tissue
 - Uses fatty acids and monoglycerides to synthesize triglycerides for storage

Module 23.10: Lipids



Lipid utilization (continued)

■ Liver

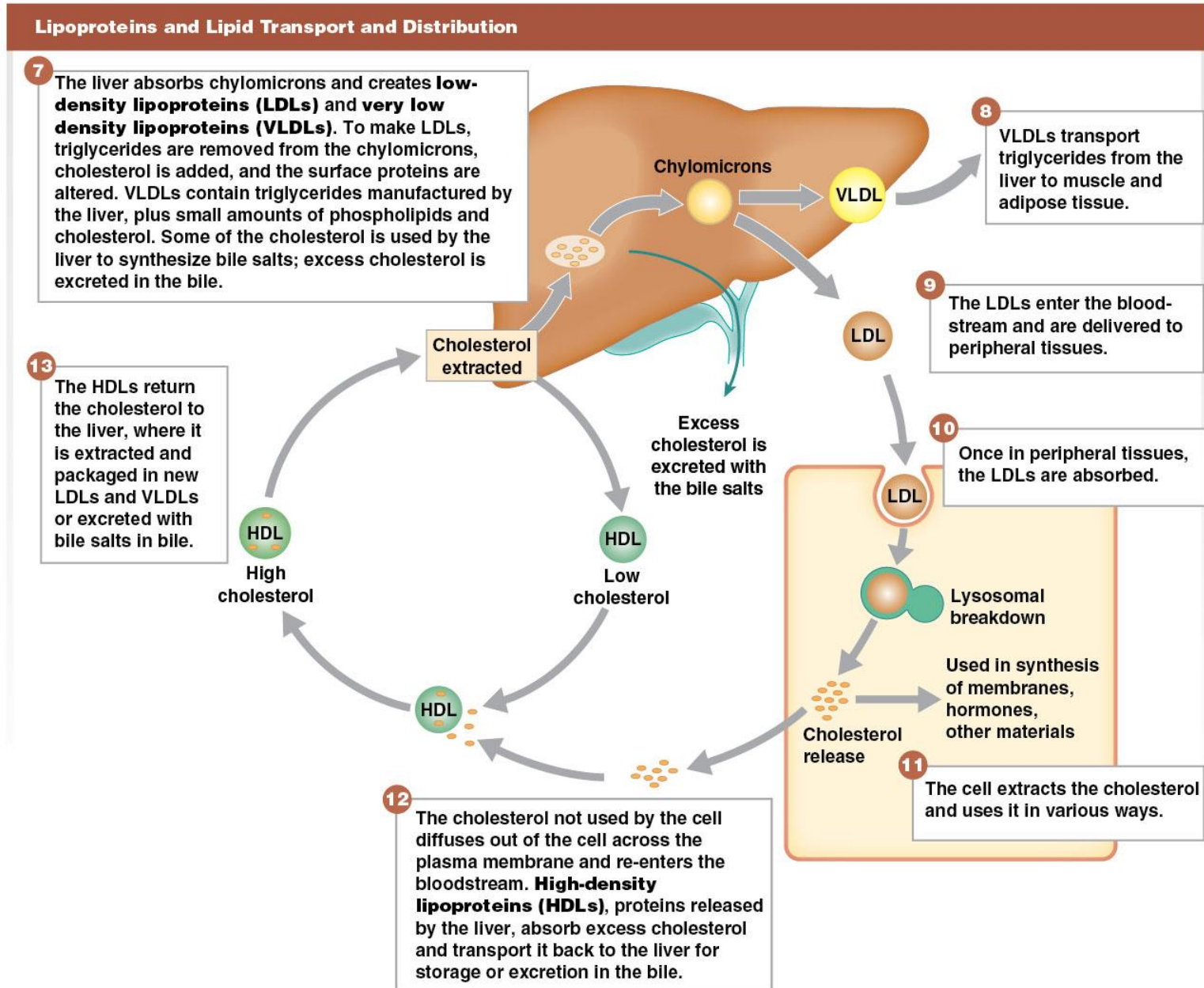
- Absorbs intact chylomicrons and extracts triglycerides and cholesterol from chylomicron

Module 23.10: Lipids

Lipid processing in the liver

- From absorbed chylomicrons, the liver removes the triglycerides, adds cholesterol, and alters the surface proteins
- Creates **low-density lipoproteins (LDLs)** and **very low density lipoproteins (VLDLs)**
 - VLDLs transport triglycerides to muscle and adipose tissue
 - LDLs deliver cholesterol to peripheral tissues
 - Cells extract and use the cholesterol to build membranes, hormones, and other materials
 - Excess cholesterol diffuses back into the bloodstream

Lipoproteins and lipid transport



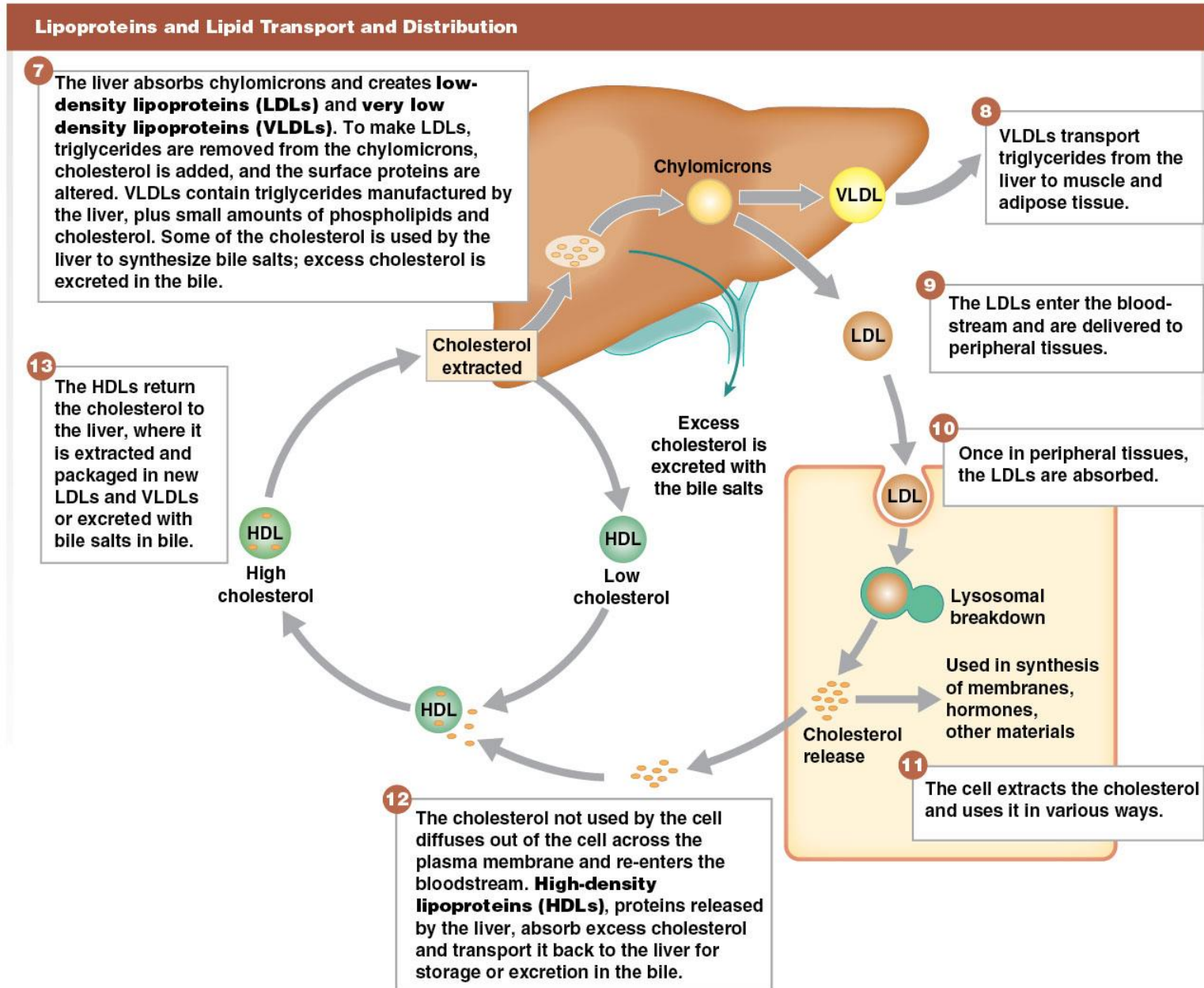
Module 23.10: Lipids

Lipid processing in the liver (continued)

■ High-density lipoproteins (HDLs)

- Proteins released by the liver
- Absorb excess cholesterol in the bloodstream and return it to the liver
- Cholesterol used to synthesize more LDLs or VLDLs
 - Also used to synthesize bile salts

Lipoproteins and lipid transport (continued)



Module 23.10: Lipids

Applications to health

- Indicators of potential cardiovascular problems
 - Total cholesterol above 200 mg/dL
 - High LDL:HDL ratio
- These values show:
 1. High levels of cholesterol in circulation
 2. Most of the cholesterol is going into the tissues and staying instead of returning to the liver
- Consequences
 - Excess cholesterol can accumulate as plaques in blood vessels, causing heart attacks and strokes

Module 23.10: Review

- A. What is the difference between a micelle and a chylomicron?
- B. What does the liver do with the chylomicrons it receives?
- C. Describe the roles of LDLs and HDLs.

Learning Outcome: Describe the mechanisms of lipid transport and distribution.

Module 23.11: Fatty acids can be broken down to provide energy or converted to other lipids

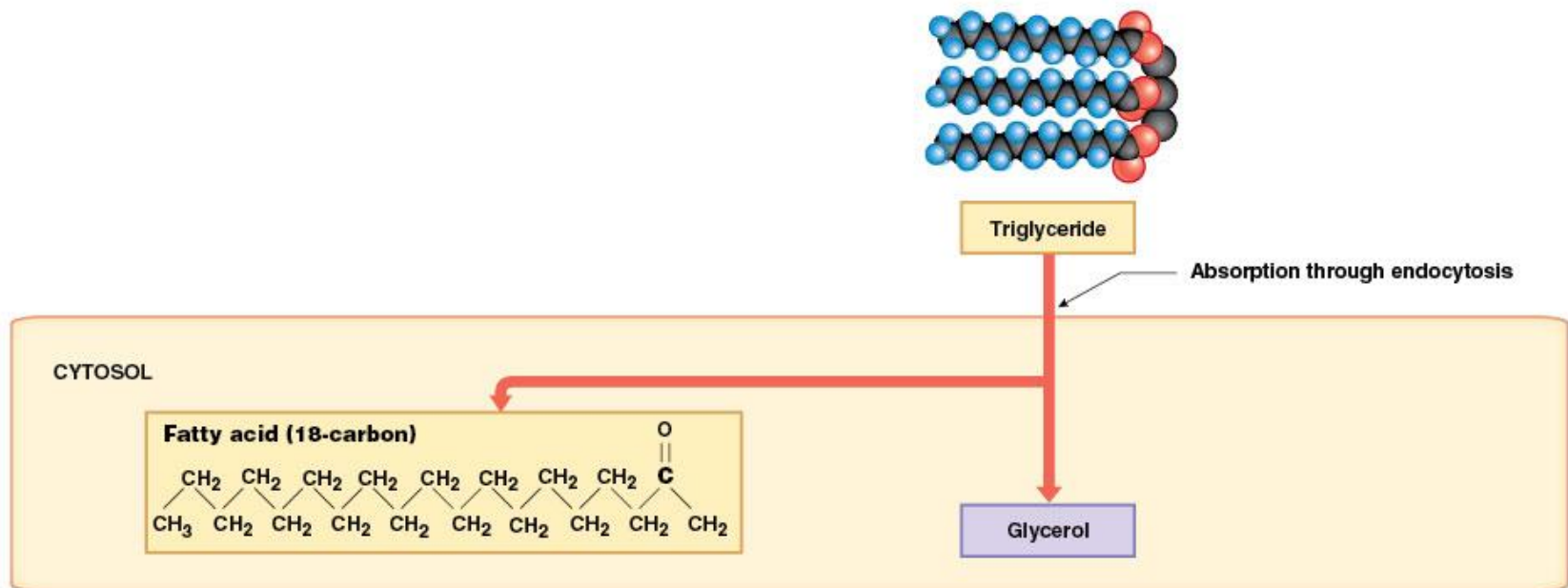
Lipolysis

- Lipid catabolism in which lipids are broken down into pieces that:
 - Can be converted to pyruvate
 - Can be channeled directly into the citric acid cycle
- More efficient than glucose catabolism
 - 6-carbon glucose yields 36 ATP
 - 6 carbons from fatty acids yield 51 ATP

Module 23.11: Lipid catabolism and synthesis

Triglyceride catabolism

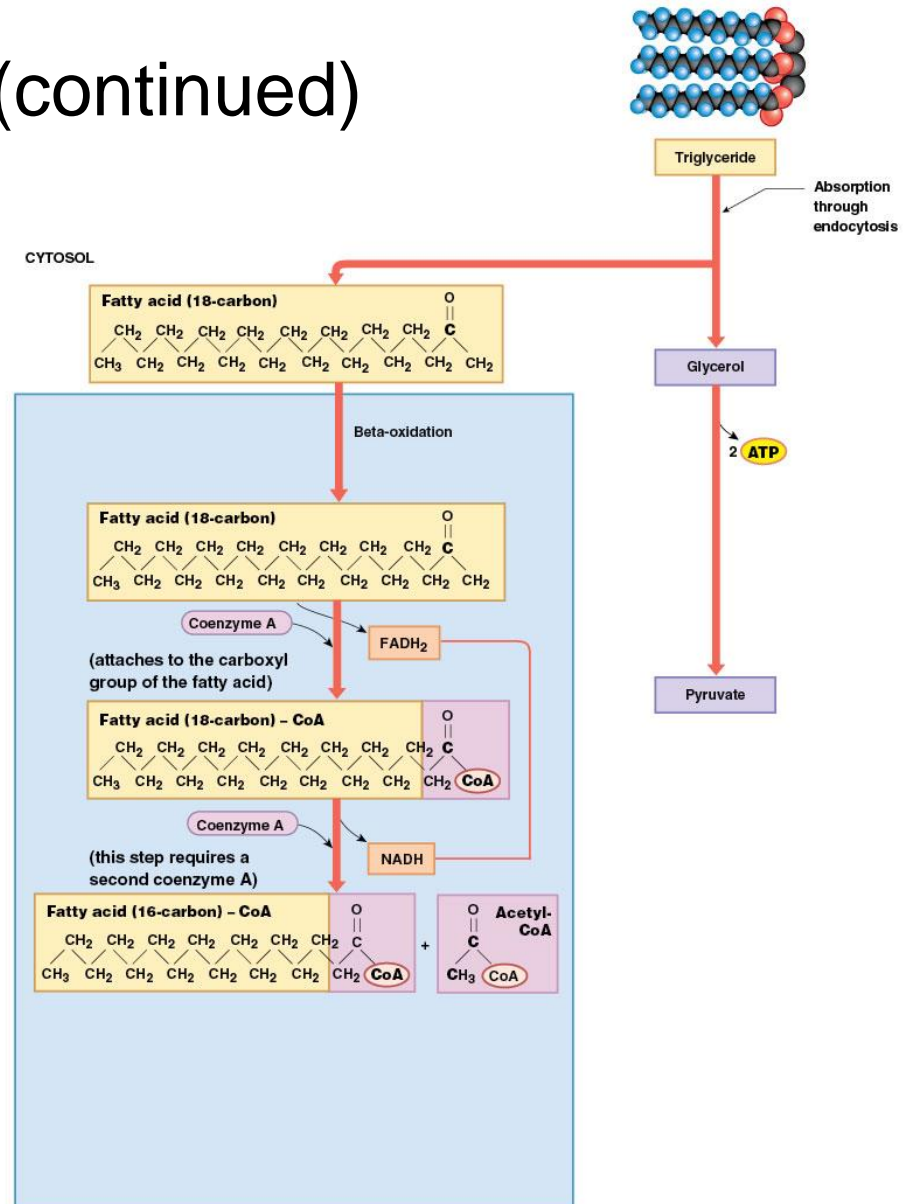
- Lysosomal enzymes break down triglycerides into:
- 1 glycerol molecule
- 3 fatty acid molecules



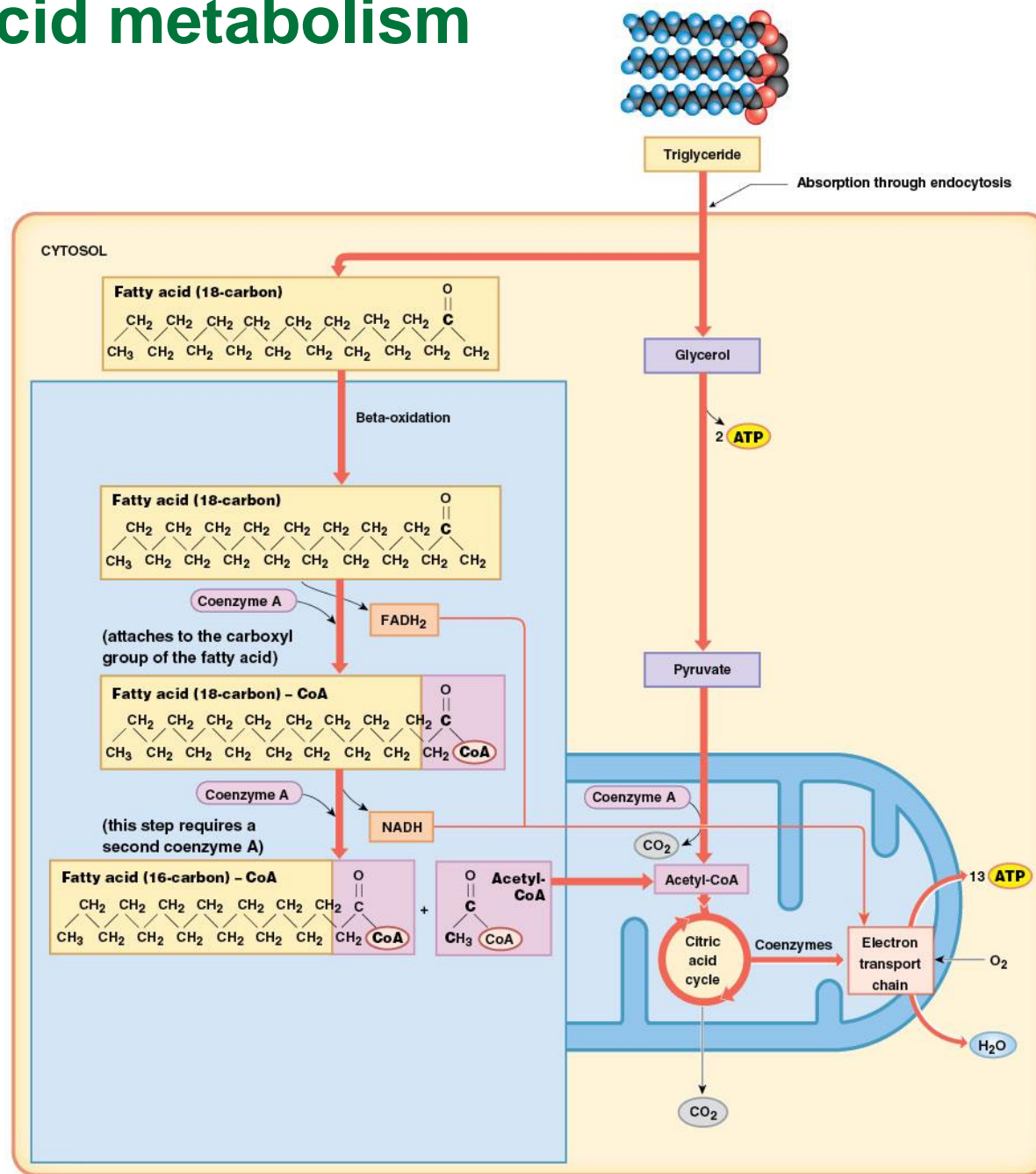
Module 23.11: Lipid catabolism and synthesis

Triglyceride catabolism (continued)

- Glycerol is converted to pyruvate in glycolysis (yields 2 ATP)
- Fatty acids are catabolized to acetyl-CoA through **beta-oxidation**



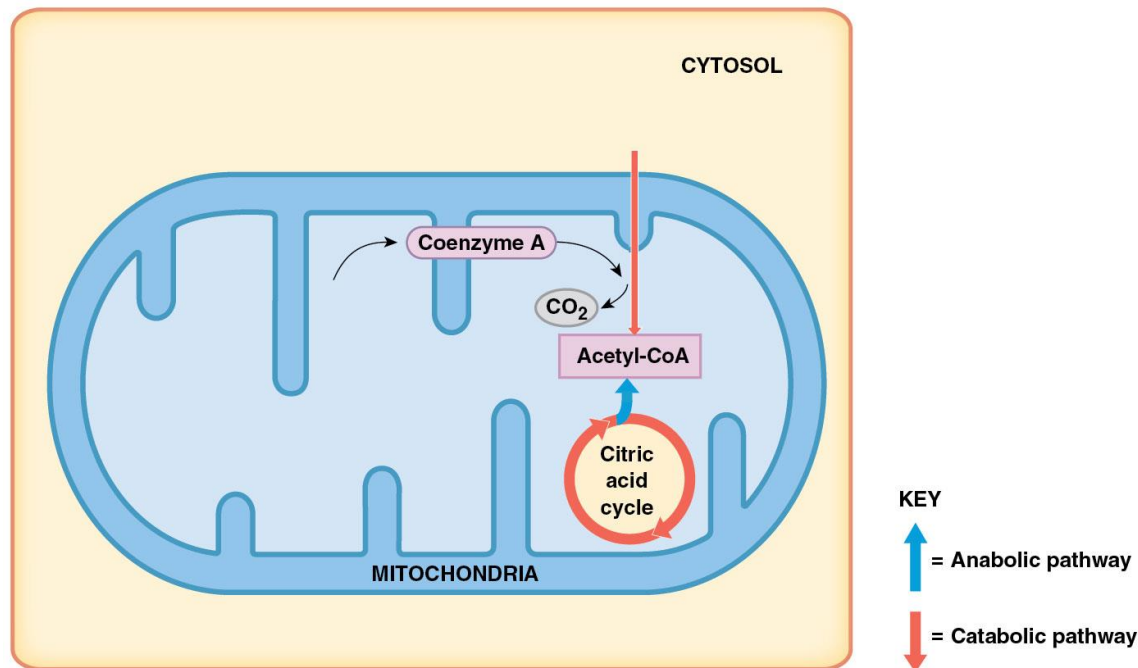
Fatty acid metabolism



Module 23.11: Lipid catabolism and synthesis

Lipogenesis

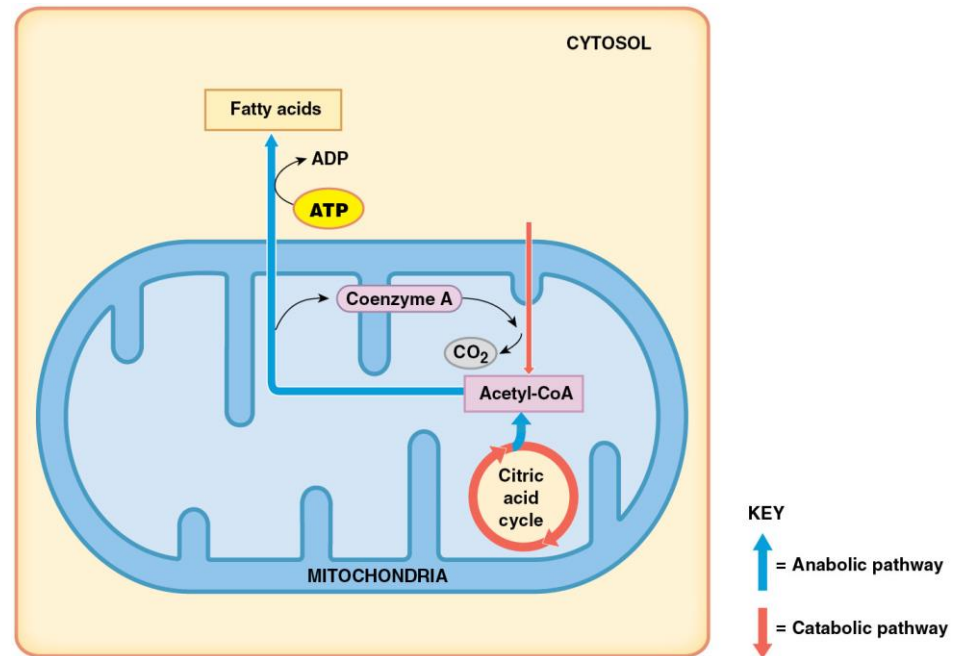
- Synthesis of lipids
- Begins with acetyl-CoA
 - Almost any organic substrate (lipids, amino acids, carbohydrates) can be converted to acetyl-CoA



Module 23.11: Lipid catabolism and synthesis

Lipogenesis (continued)

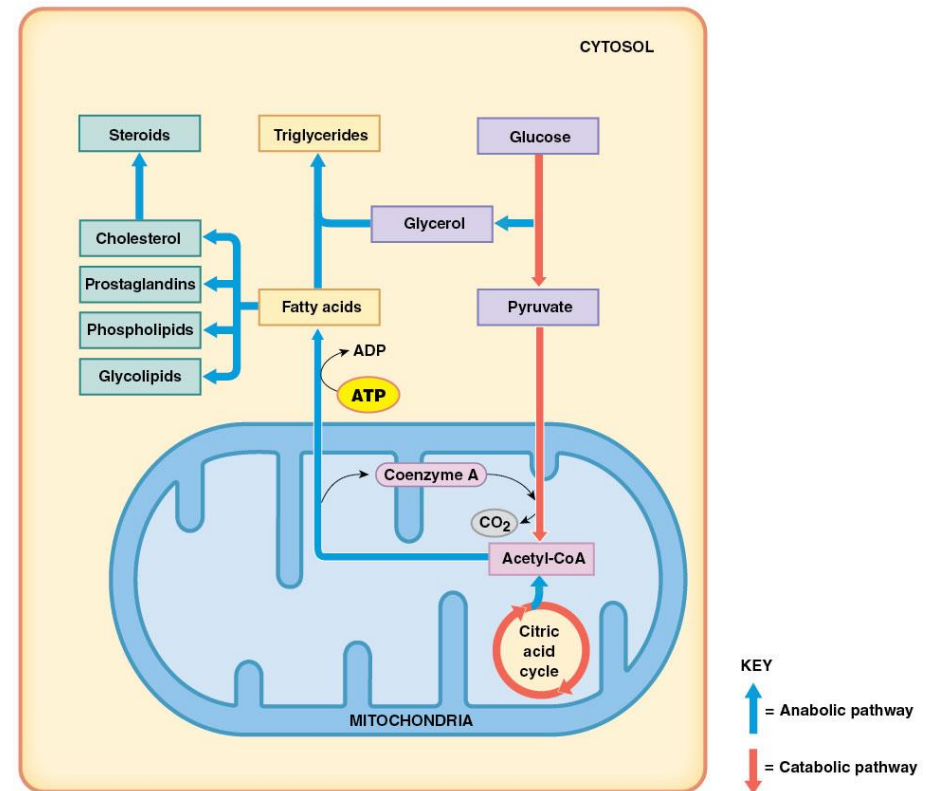
- Some fatty acids are synthesized from acetyl-CoA
 - Involves a series of enzymatic steps different from beta-oxidation, using different enzymes
- **Essential fatty acids**
 - Cannot be synthesized; must be obtained from diet
 - *Examples: linolenic acid (omega-3 fatty acid) and linoleic acid (omega-6 fatty acid)*



Module 23.11: Lipid catabolism and synthesis

Lipogenesis (continued)

- Structural and functional lipids are created from fatty acids
- Glycerol is synthesized from intermediate products of glycolysis
- Fatty acids + glycerol = triglycerides



Module 23.11: Lipid catabolism and synthesis

Lipids as energy reserves

- Useful because:
 - Beta-oxidation is very efficient
 - Excess lipids can be easily stored as triglycerides
- However:
 - Cannot provide large amounts of ATP quickly
 - Difficult for water-soluble enzymes to access the insoluble droplets
 - Well suited for chronic energy demands during stress or starvation

Module 23.11: Review

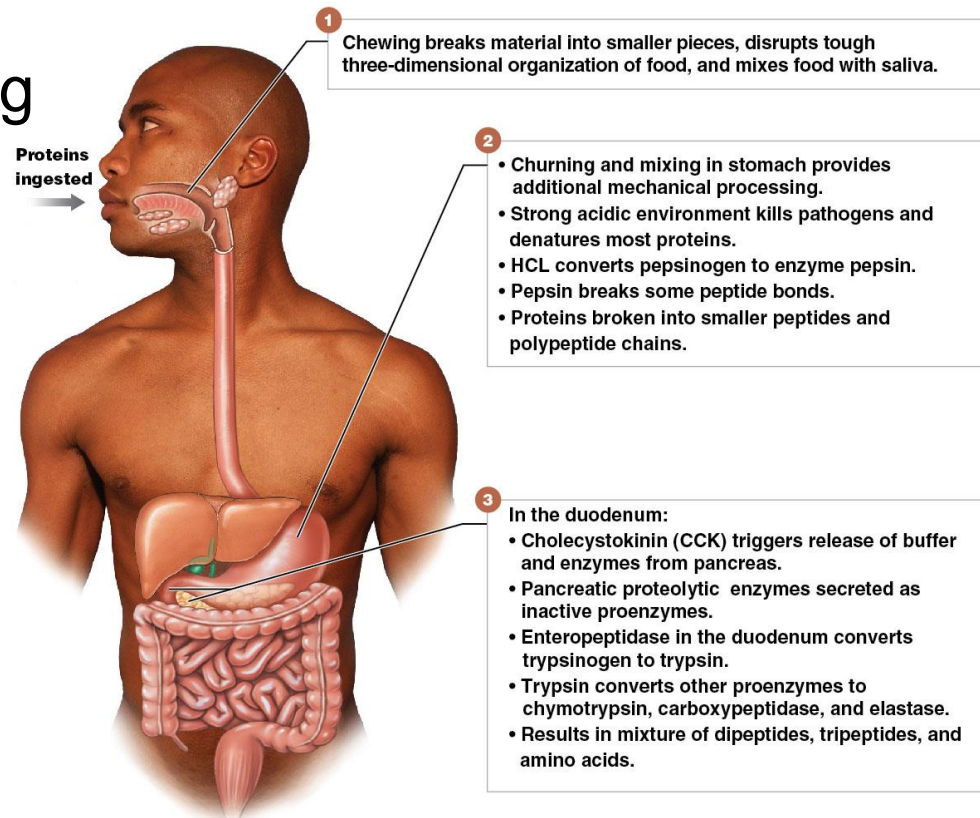
- A. Define *beta-oxidation*.
- B. Which molecule is a key reactant in both ATP production from fatty acids and lipogenesis?
- C. Identify the fates of fatty acids.

Learning Outcome: Describe the fate of fatty acids in lipid metabolism.

Module 23.12: An amino acid not needed for protein synthesis may be broken down or converted to a different amino acid

Protein digestion

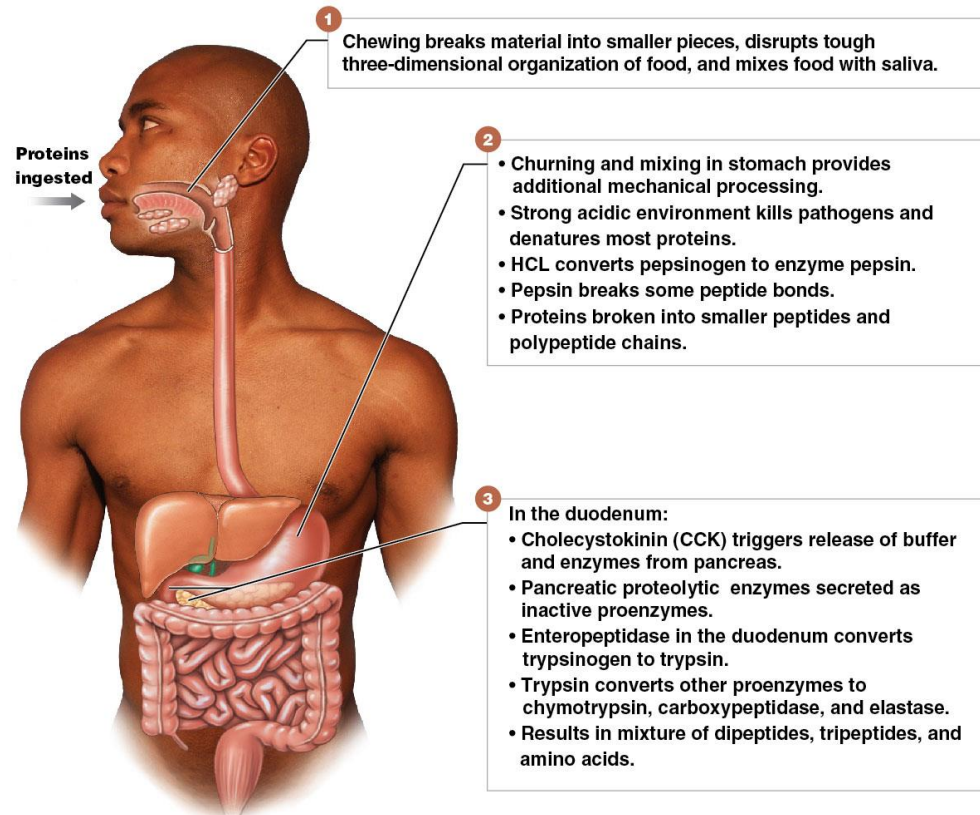
- In the mouth, mechanical processing occurs
- In the stomach
 - Mechanical processing continues with churning and mixing



Module 23.12: Proteins

Protein digestion (continued)

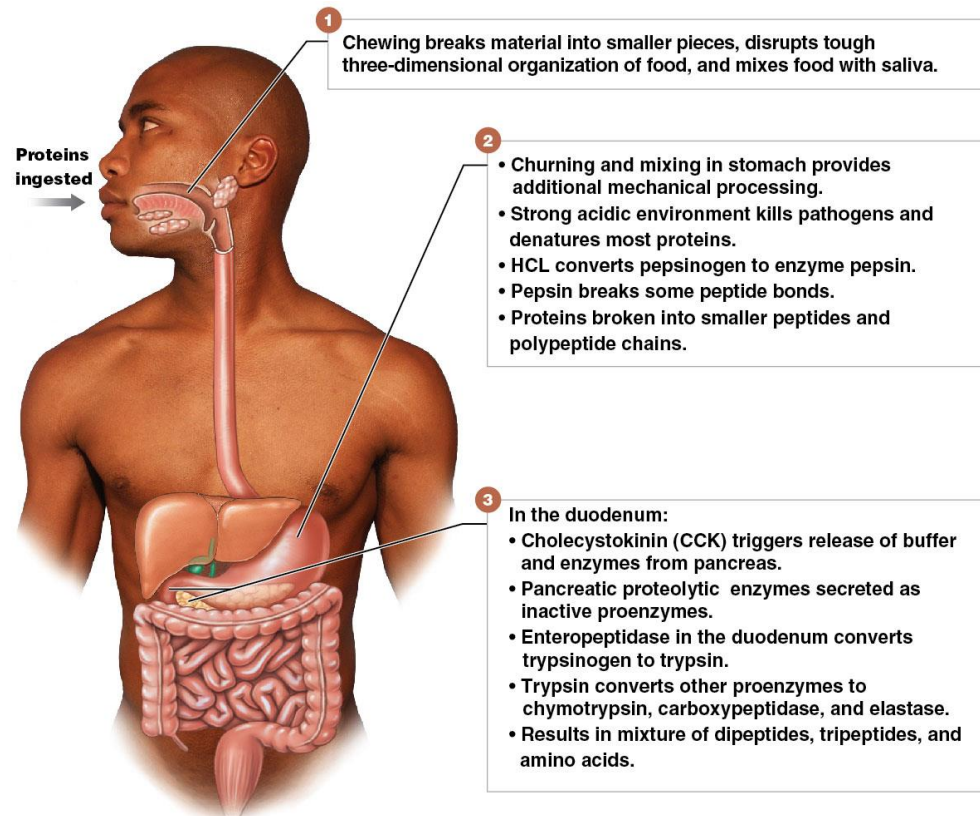
- In the stomach (continued)
 - Chemical digestion begins
 - Strong acid environment denatures proteins, disrupting secondary and tertiary structures



Module 23.12: Proteins

Protein digestion (continued)

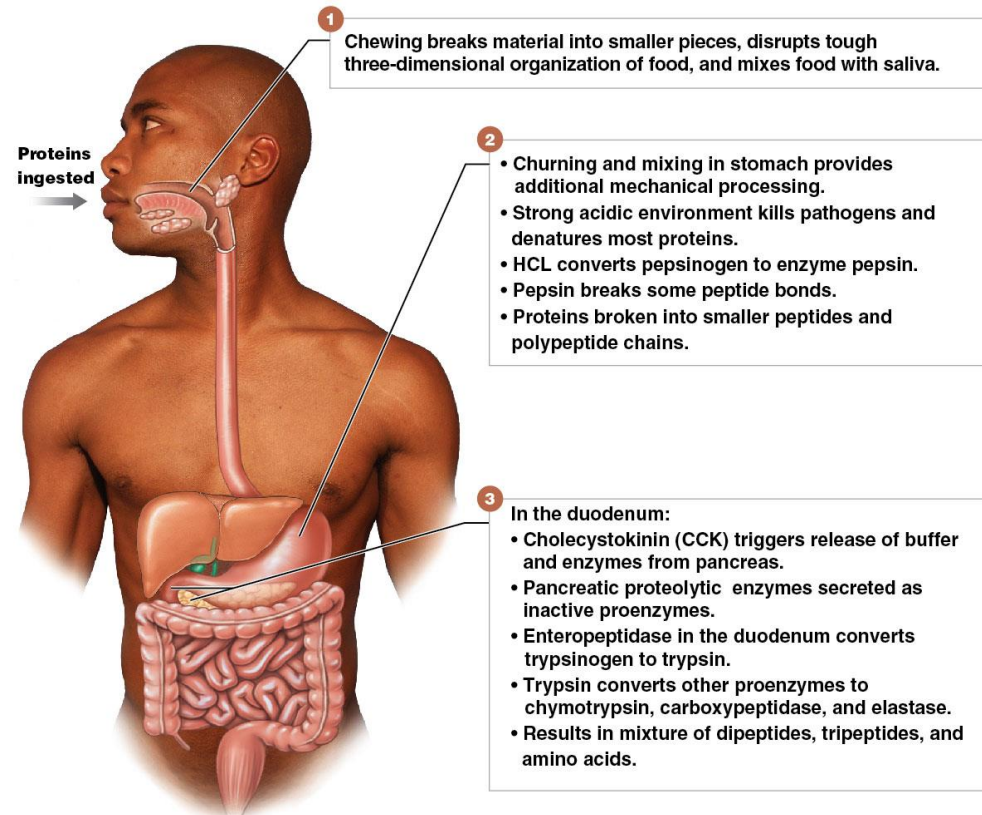
- In the stomach (continued)
 - Chemical digestion (continued)
 - Peptide bonds are attacked by **pepsin** (secreted from chief cells)
 - Digests proteins into smaller peptide and polypeptide chains



Module 23.12: Proteins

Protein digestion (continued)

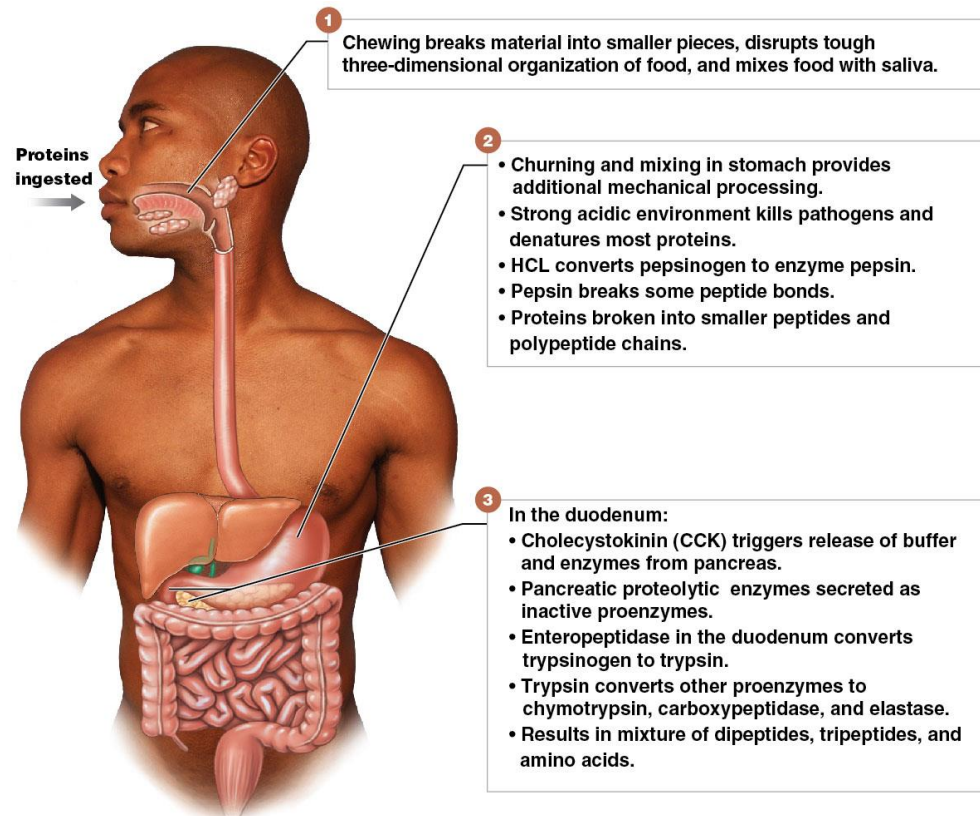
- In the duodenum
 - CCK stimulates secretion of pancreatic enzymes (released as inactive proenzymes)



Module 23.12: Proteins

Protein digestion (continued)

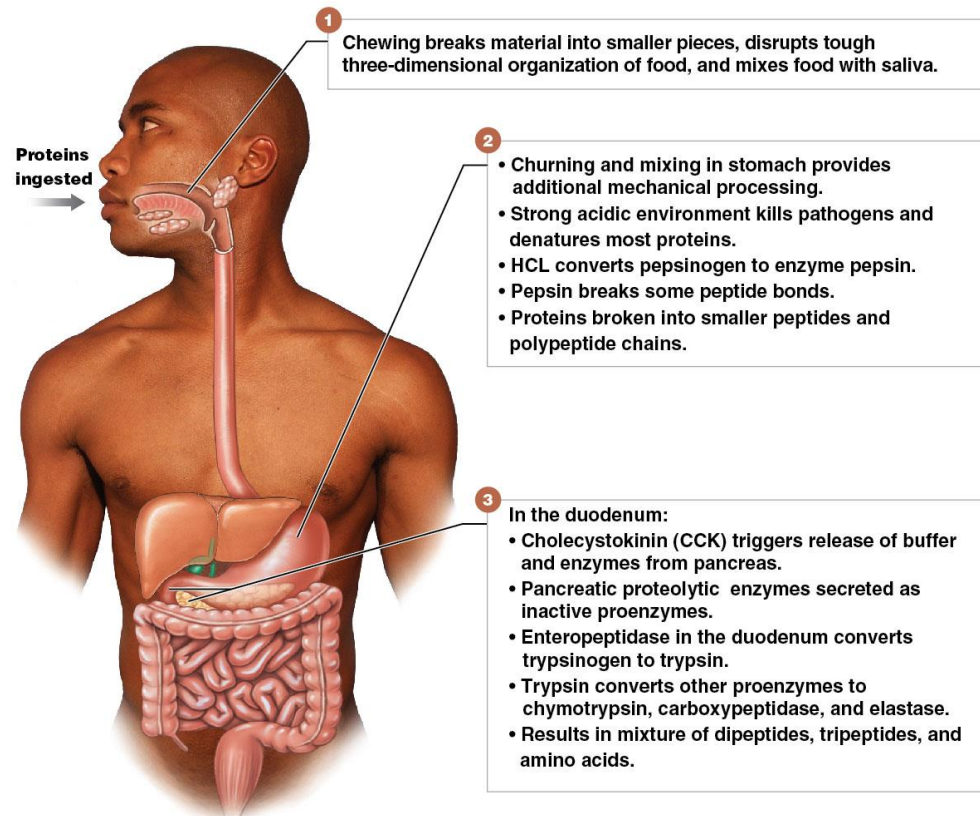
- In the duodenum (continued)
 - **Enteropeptidase** (from the duodenal epithelium) converts trypsinogen to **trypsin**



Module 23.12: Proteins

Protein digestion (continued)

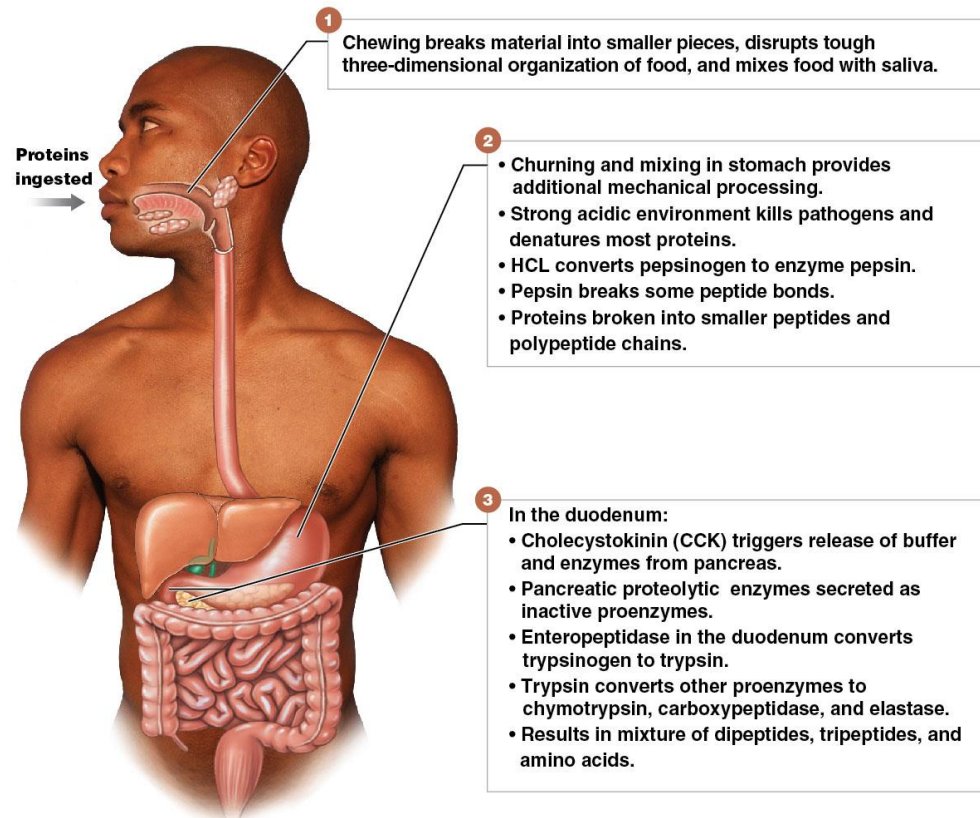
- In the duodenum (continued)
 - **Trypsin** activates other pancreatic proenzymes to their active forms
 - **Chymotrypsin, carboxypeptidase, and elastase**



Module 23.12: Proteins

Protein digestion (continued)

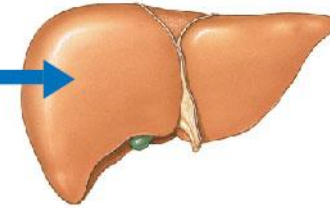
- In the duodenum (continued)
 - Activated pancreatic enzymes digest specific peptide bonds, producing short peptides and amino acids



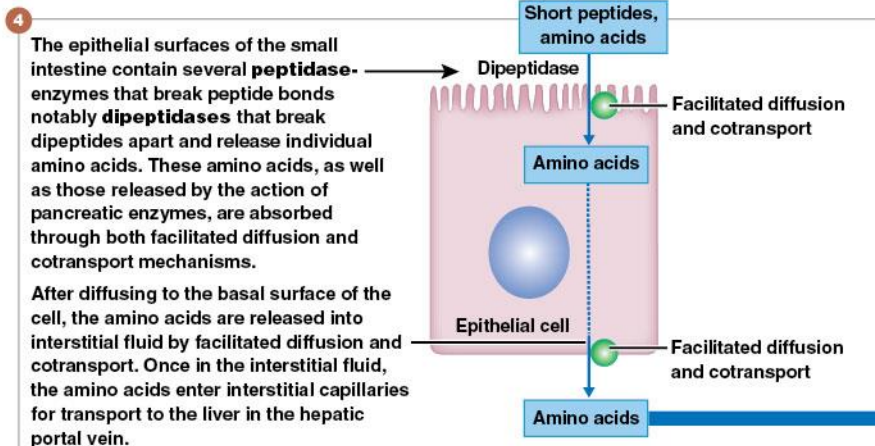
Module 23.12: Proteins

- **Peptidases** from the small intestine epithelium
 - Break peptide bonds and release amino acids
 - *Example: dipeptidases* break dipeptides into single amino acids

5 Blood amino acid levels normally range between 35 and 65 mg/dL, but they may become elevated after a protein-rich meal. The liver itself uses many amino acids for synthesizing plasma proteins, and it has all of the enzymes needed to synthesize, convert, or catabolize amino acids. In addition, amino acids that can be broken down to 3-carbon molecules can be used for gluconeogenesis when other sources of glucose are unavailable.



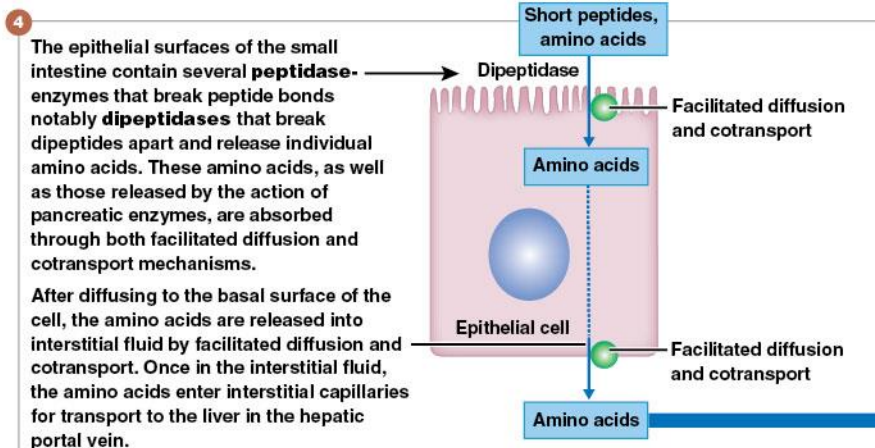
Hepatic portal vein



Module 23.12: Proteins

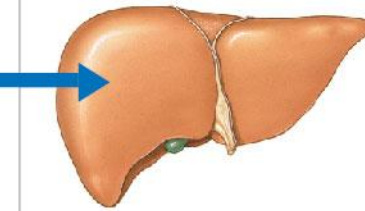
Protein absorption and transport

- Short peptides and amino acids are absorbed into epithelial cells by:
 - Facilitated diffusion
 - Cotransport



5

Blood amino acid levels normally range between 35 and 65 mg/dL, but they may become elevated after a protein-rich meal. The liver itself uses many amino acids for synthesizing plasma proteins, and it has all of the enzymes needed to synthesize, convert, or catabolize amino acids. In addition, amino acids that can be broken down to 3-carbon molecules can be used for gluconeogenesis when other sources of glucose are unavailable.



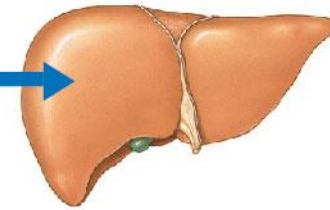
Hepatic portal vein

Module 23.12: Proteins

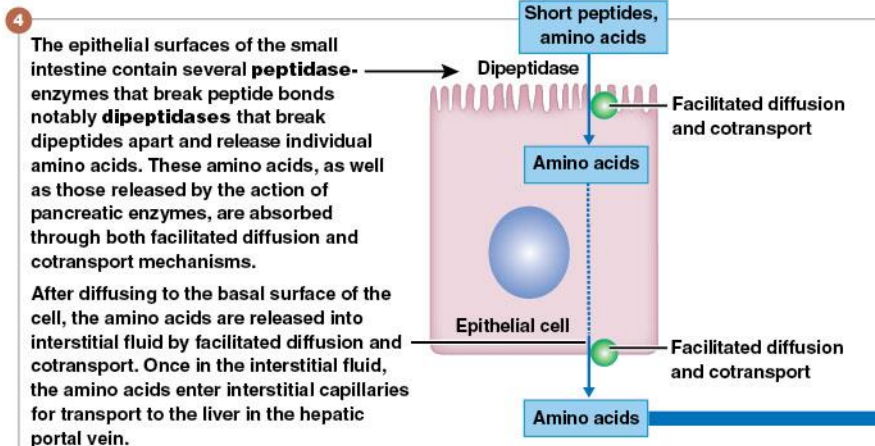
Protein absorption and transport (continued)

- Amino acids are transported to liver through intestinal capillaries to hepatic portal vein

5 Blood amino acid levels normally range between 35 and 65 mg/dL, but they may become elevated after a protein-rich meal. The liver itself uses many amino acids for synthesizing plasma proteins, and it has all of the enzymes needed to synthesize, convert, or catabolize amino acids. In addition, amino acids that can be broken down to 3-carbon molecules can be used for gluconeogenesis when other sources of glucose are unavailable.



Hepatic portal vein

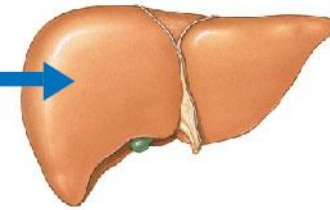


Module 23.12: Proteins

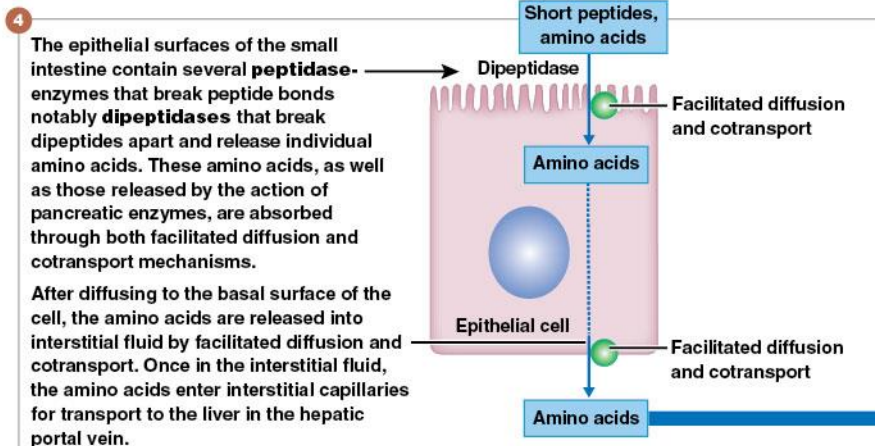
Protein absorption and transport (continued)

- In the liver
 - Control of plasma amino acid levels is less precise than glucose

5 Blood amino acid levels normally range between 35 and 65 mg/dL, but they may become elevated after a protein-rich meal. The liver itself uses many amino acids for synthesizing plasma proteins, and it has all of the enzymes needed to synthesize, convert, or catabolize amino acids. In addition, amino acids that can be broken down to 3-carbon molecules can be used for gluconeogenesis when other sources of glucose are unavailable.



Hepatic portal vein

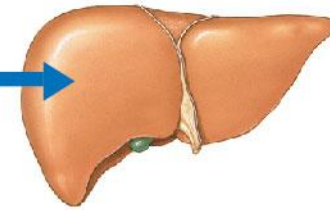


Module 23.12: Proteins

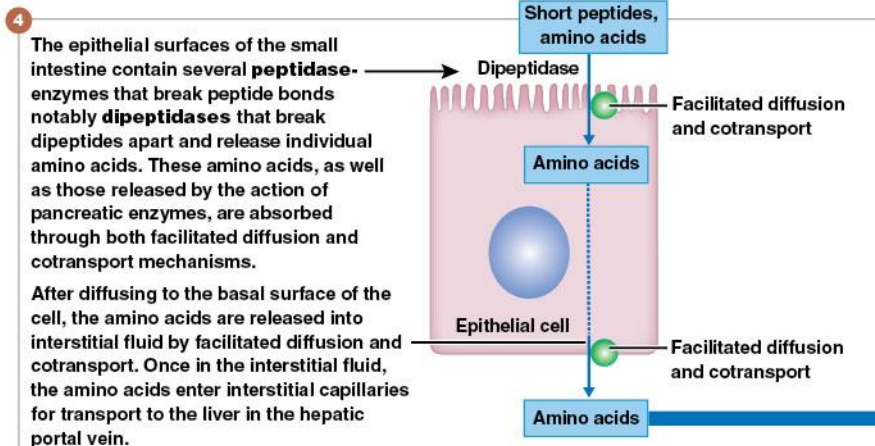
Protein absorption and transport (continued)

- In the liver (continued)
 - Liver uses amino acids to:
 - Synthesize plasma proteins
 - Create 3-carbon molecules for gluconeogenesis

5 Blood amino acid levels normally range between 35 and 65 mg/dL, but they may become elevated after a protein-rich meal. The liver itself uses many amino acids for synthesizing plasma proteins, and it has all of the enzymes needed to synthesize, convert, or catabolize amino acids. In addition, amino acids that can be broken down to 3-carbon molecules can be used for gluconeogenesis when other sources of glucose are unavailable.



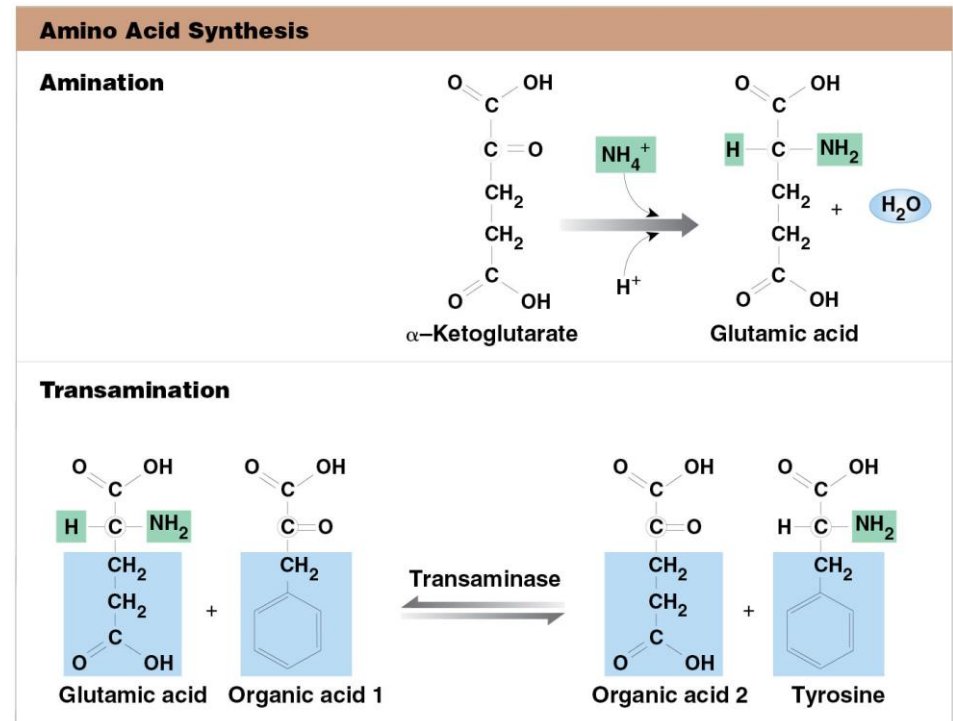
Hepatic portal vein



Module 23.12: Proteins

Amino acid synthesis

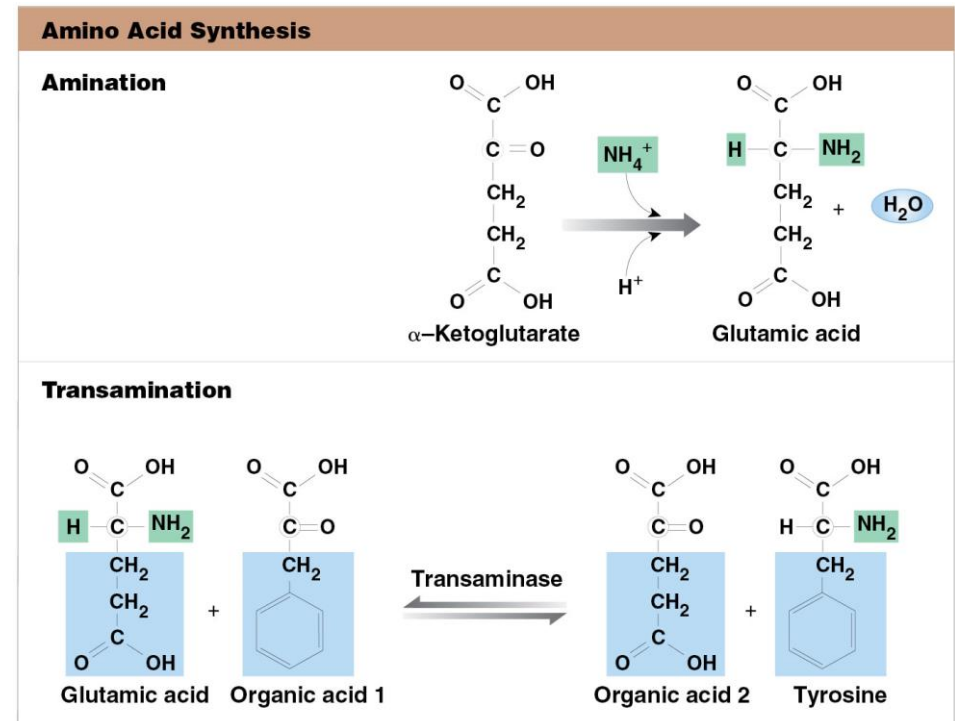
- Liver and body cells can produce 10 of the 20 amino acids required to synthesize needed proteins
 - Remaining 10 are **essential amino acids**
 - Cannot be produced



Module 23.12: Proteins

Amino acid synthesis (continued)

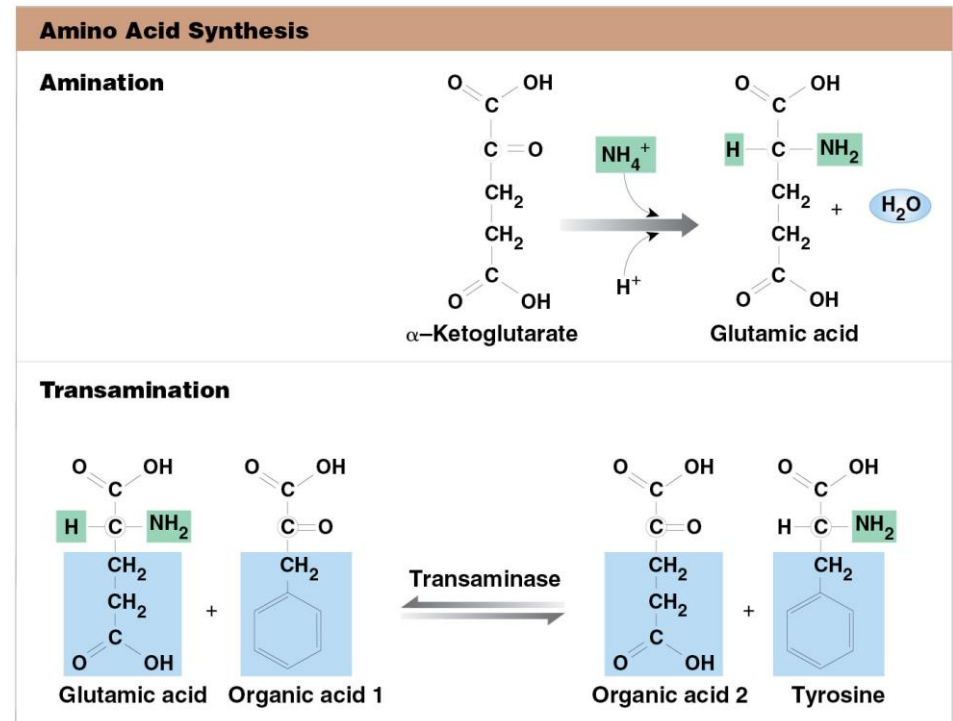
- Two methods of forming amino acids
 - **Amination**
 - Using an ammonium ion to form an amino group and attaching that group to a molecule



Module 23.12: Proteins

Amino acid synthesis (continued)

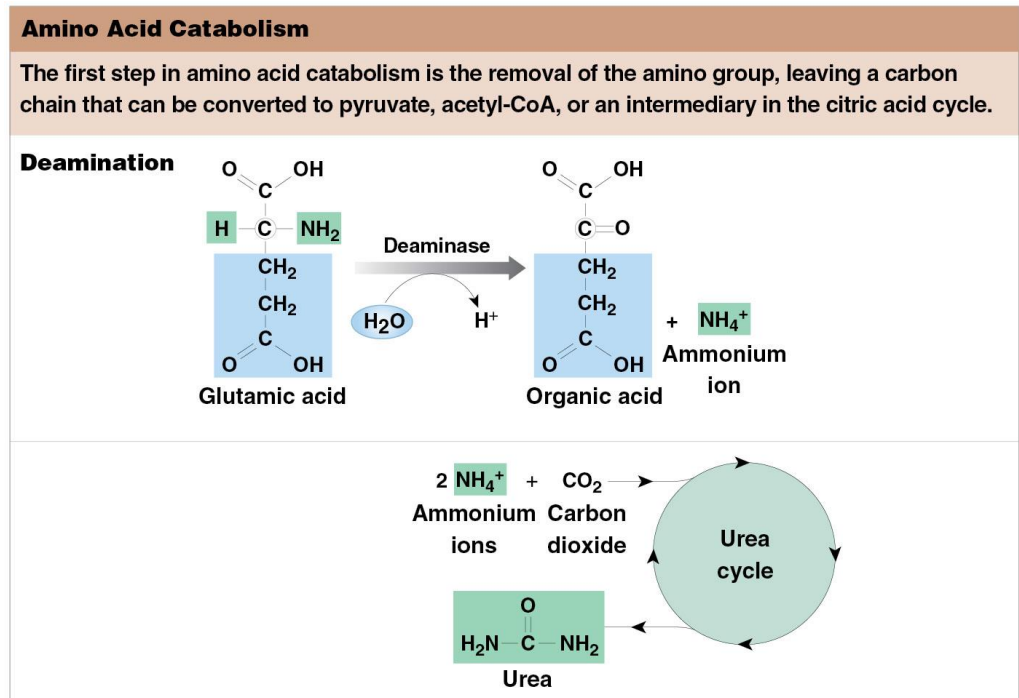
- Two methods of forming amino acids (continued)
 - **Transamination**
 - Transferring an amino group to another molecule, yielding a different amino acid



Module 23.12: Proteins

Amino acid catabolism

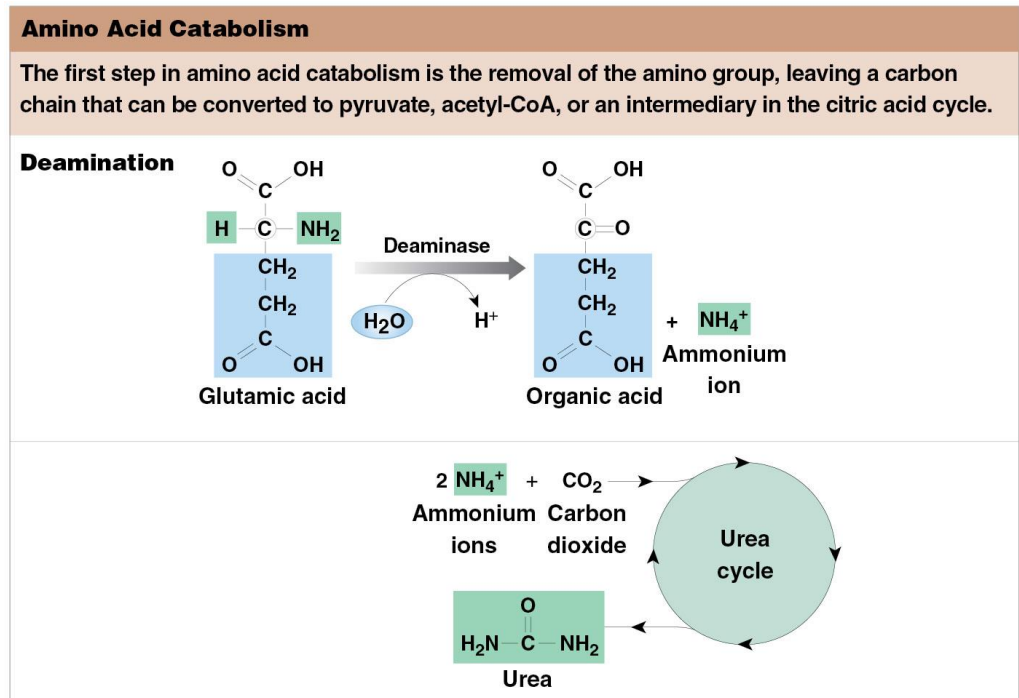
- Requires the removal of the amino group
 - Removal can be by **transamination** (transfer to another molecule)
 - Actual process of removal is called **deamination**



Module 23.12: Proteins

Amino acid catabolism (continued)

- Releases ammonium ions, which are toxic
- Enzymes in liver cells use ammonium ions to synthesize **urea**
 - Process called the **urea cycle**
 - Urea is then excreted in urine



Module 23.12: Review

- A. Describe the role of CCK release and its effects on proteins.
- B. In amino acid metabolism, identify the processes by which the amino group is removed.
- C. What happens to the ammonium ions that are removed from amino acids during deamination?

Learning Outcome: Summarize the main features of protein metabolism and the use of proteins as an energy source.

Module 23.13: There are two general patterns of metabolic activity: the absorptive and postabsorptive states

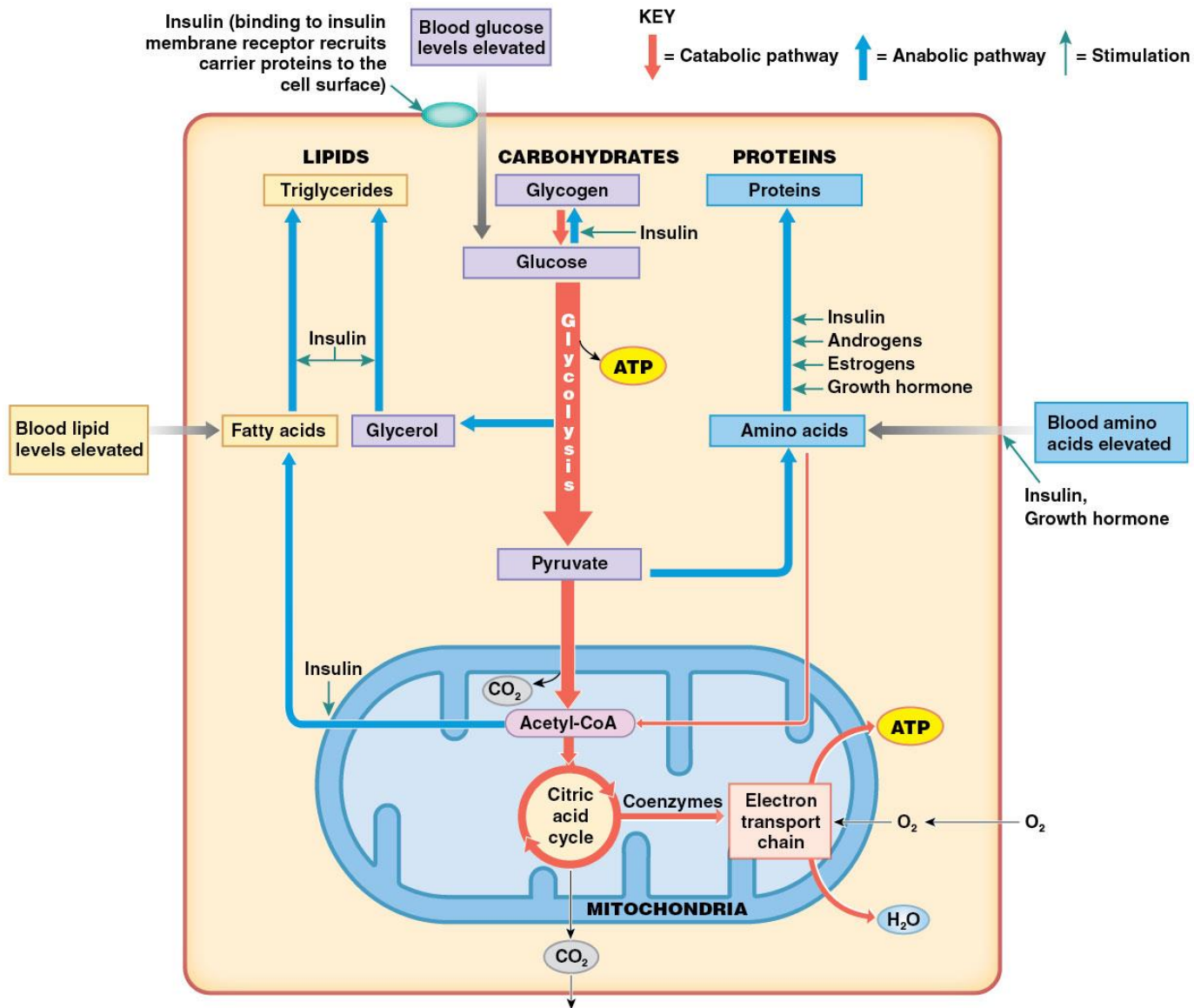
Absorptive state

- Time following a meal, when nutrient absorption is occurring
- Typically continues for ~4 hours
- Insulin is primary regulating hormone

In the Absorptive State

- Insulin stimulates (1) glucose uptake and glycogenesis, (2) amino acid uptake and protein synthesis, and (3) triglyceride synthesis.
- Androgens, estrogens, and growth hormone also stimulate protein synthesis.
- Glycolysis and aerobic metabolism provide the ATP needed to power cellular activities as well as the synthesis of lipids and proteins.

Absorptive state



Module 23.13: Absorptive and postabsorptive states

Postabsorptive state

- Time when nutrient absorption is not occurring and body relies on internal energy reserves
- Metabolic activity focused on mobilizing energy reserves and maintaining blood glucose
- Coordinated by several hormones
 - Glucagon, epinephrine, glucocorticoids, growth hormone

In the Postabsorptive State

- Glucocorticoids stimulate the mobilization of lipid and protein reserves; these effects are enhanced by growth hormone.
- Glucagon stimulates glycogenolysis and gluconeogenesis, primarily in the liver. The release of glucose by the liver and the shift away from glucose metabolism by other tissues stabilizes blood glucose levels.
- Epinephrine is important in stimulating glycogenolysis in skeletal and cardiac muscle, and lipolysis in adipocytes.

Module 23.13: Absorptive and postabsorptive states

Postabsorptive state (continued)

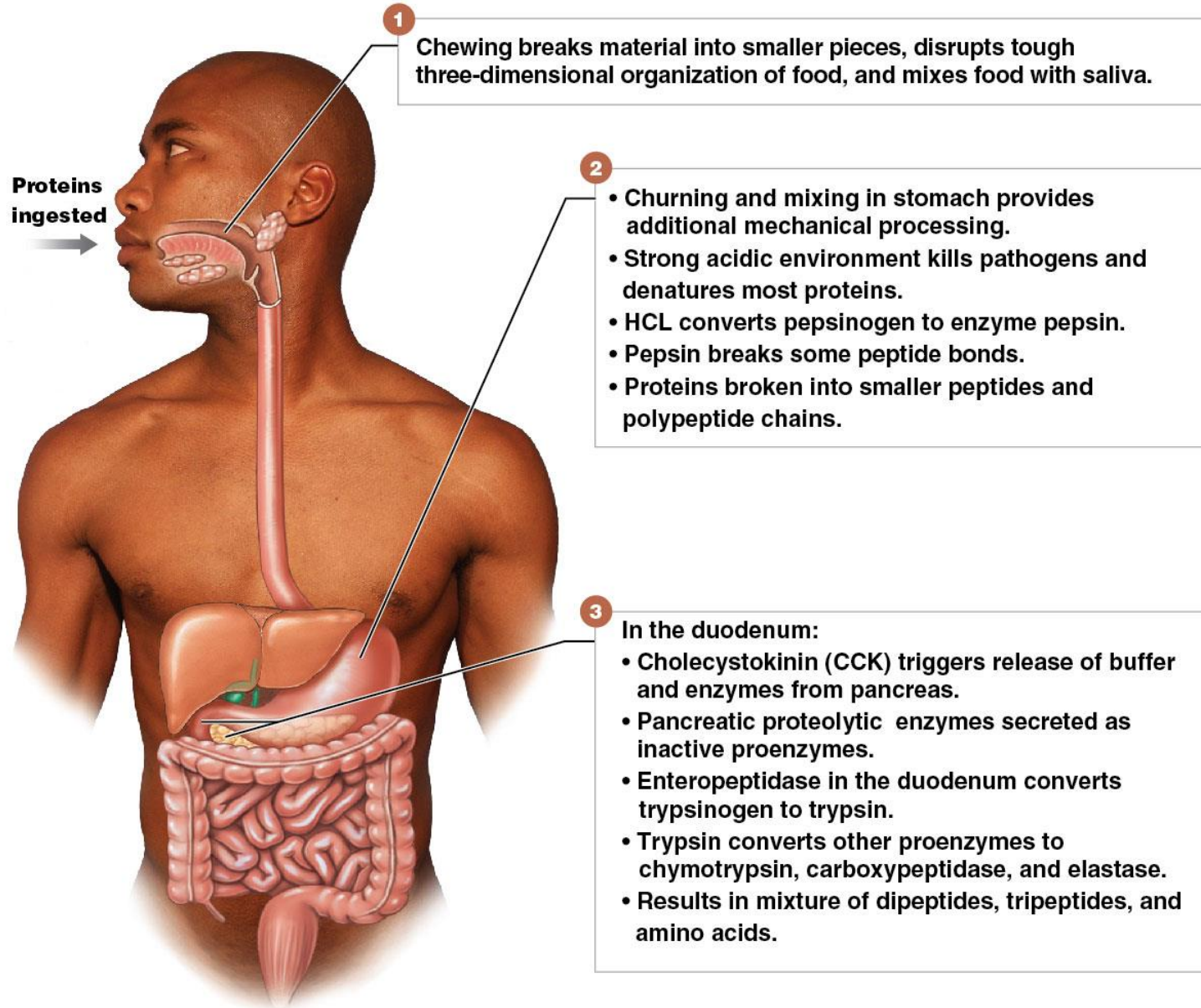
- Blood lipid levels decrease
 - Response is release of fatty acids by adipocytes
- Blood amino acid levels decrease
 - Response is amino acid release by skeletal muscles and other tissues
- Blood glucose levels decrease
 - Response is glucose release by liver

Module 23.13: Absorptive and postabsorptive states

Postabsorptive state (continued)

- Catabolism of lipids and amino acids in liver produce acetyl-CoA
 - Leads to formation of **ketone bodies**
 - Diffuse into blood and are used by other cells as energy source

Postabsorptive state



Module 23.13: Review

- A. Define and describe the *absorptive state*.
- B. When and how do ketone bodies form?
- C. How do the absorptive and postabsorptive states maintain normal blood glucose levels?

Learning Outcome: Differentiate between the absorptive and postabsorptive metabolic states, and summarize the characteristics of each.

Module 23.14: Vitamins are essential to the function of many metabolic pathways

Nutrition

- Absorption of nutrients from food

Vitamins

- Organic compounds required in very small quantities for essential metabolic activities
- Two classes
 - **Fat-soluble vitamins**
(A, D₃, E, and K)
 - **Water-soluble vitamins**
(B vitamins and C)



Module 23.14: Vitamins

Minerals

- Inorganic nutrients that serve as electrolytes in body fluids



Module 23.14: Vitamins

Fat-soluble vitamins

- Absorbed primarily from digestive tract with lipid contents of micelles
- Sources
 - Vegetables for vitamins A, E, K
 - Vitamin D₃ is produced in skin when exposed to sunlight
 - Vitamin K is produced by intestinal bacteria
- Stored in lipid deposits
 - Give large bodily reserves
 - Normal metabolic activities can continue for months without a dietary source

The Fat-Soluble Vitamins

Vitamin	Significance	Sources	Recommended Daily Allowance (RDA) in mg	Effects of Deficiency	Effects of Excess
A	Maintains epithelia; required for synthesis of visual pigments; supports immune system; promotes growth and bone remodeling	Leafy green and yellow vegetables, liver, dairy products, and fish	0.7–0.9	Retarded growth, night blindness, deterioration of epithelial membranes	Liver damage, skin paling, CNS effects (nausea, anorexia)
D	Required for normal bone growth, intestinal calcium and phosphorus absorption, and retention of these ions by the kidneys	Synthesized in skin exposed to sunlight; fortified dairy products and egg yolks	0.005–0.015*	Rickets, skeletal deterioration	Calcium deposits in many tissues, disrupting functions
E	Prevents breakdown of vitamin A and fatty acids	Meat, milk, vegetables	15	Anemia, other problems suspected	Nausea, stomach cramps, blurred vision, fatigue
K	Essential for liver synthesis of prothrombin and other clotting factors	Vegetables; production by intestinal bacteria	0.09–0.12	Bleeding disorders	Liver dysfunction, jaundice

Module 23.14: Vitamins

■ Hypovitaminosis

- Vitamin deficiency disease
- Rarely occurs with fat-soluble vitamins (except for vitamin D₃)

■ Hypervitaminosis

- Dietary intake exceeds the body's ability to store, utilize, or excrete vitamins
- Can occur because metabolism from lipid reserves takes time
- Potentially harmful

Module 23.14: Vitamins

Water-soluble vitamins

- Most are components of coenzymes
- Nutritional sources
 - B vitamins are found in meat, eggs, and dairy products
 - Vitamin C is found in citrus fruits
- Rapidly exchanged between digestive tract and blood
- Excess amounts readily excreted in urine
 - Hypervitaminosis rarely occurs unless ingesting megadoses of vitamin supplements

Module 23.14: Vitamins

Water-soluble vitamins (continued)

- Most water-soluble vitamins are not stored in the body in significant amounts
 - Vitamins B₁₂ and C are the exceptions
- All but one are absorbed easily across the intestinal epithelium
 - Vitamin B₁₂ has to bind to **intrinsic factor** to be absorbed
- Insufficient intake can lead to initial symptoms of vitamin deficiency in days to weeks
- Intestinal bacteria produce small amounts of four vitamins (B₅, B₇, B₉, B₁₂)

The Water-Soluble Vitamins

Vitamin	Component or Precursor of	Sources	Recommended Daily Allowance (RDA) in mg	Effects of Deficiency	Effects of Excess
B ₁ (thiamine)	Coenzyme in many pathways	Milk, meat, bread	1.1–1.2	Muscle weakness, CNS and cardiovascular problems, including heart disease; called <i>beriberi</i>	Hypotension
B ₂ (riboflavin)	Part of FAD, involved in multiple pathways, including glycolysis and citric acid cycle	Milk, meat, eggs and cheese	1.1–1.3	Epithelial and mucosal deterioration	Itching, tingling
B ₃ (niacin)	Part of NAD, involved in multiple pathways	Meat, bread, potatoes	14–16	CNS, GI, epithelial, and mucosal deterioration; called <i>pellagra</i>	Itching, burning; vasodilation; death after large dose
B ₅ (pantothenic acid)	Coenzyme A, in multiple pathways	Milk, meat	10	Retarded growth, CNS disturbances	None reported
B ₆ (pyridoxine)	Coenzyme in amino acid and lipid metabolism	Meat, whole grains, vegetables, orange juice, cheese and milk	1.3–1.7	Retarded growth, anemia, convulsions, epithelial changes	CNS alterations, perhaps fatal
B ₉ (folic acid)	Coenzyme in amino acid and nucleic acid metabolism	Leafy vegetables, some fruits, liver, cereal and bread	0.2–0.4	Retarded growth, anemia, gastrointestinal disorders, developmental abnormalities	Few noted, except at massive doses
B ₁₂ (cobalamin)	Coenzyme in nucleic acid metabolism	Milk, meat	0.0024	Impaired RBC production, causing pernicious anemia	Polycythemia
B ₇ (biotin)	Coenzyme in many pathways	Eggs, meat, vegetables	0.03	Fatigue, muscular pain, nausea, dermatitis	None reported
C (ascorbic acid)	Coenzyme in many pathways	Citrus fruits	75–90; smokers add 35 mg	Epithelial and mucosal deterioration; called <i>scurvy</i>	Kidney stones

Module 23.14: Review

- A. Define *nutrition*.
- B. Identify the two classes of vitamins.
- C. If vitamins do not provide a source of energy, what is their role in nutrition?

Learning Outcome: Explain the role of fat-soluble vitamins and water-soluble vitamins in metabolic pathways.

Module 23.15: Proper nutrition depends on eating a balanced diet

Balanced diet

- Contains all ingredients needed to maintain homeostasis
 - Substrates for ATP production
 - Essential amino acids
 - Fatty acids
 - Vitamins
 - Electrolytes
 - Water
- **Malnutrition**
 - Unhealthy state from inadequate or excessive nutrient absorption

Know the Limits on Fats, Sugars, and Salt (Sodium)

- Get most of your fat from fish, nuts, and vegetable oils, which are key sources of essential fatty acids.
- Limit solid fats like butter, shortening, and lard that are high in saturated fats and cholesterol.
- Check the Nutrition Facts label to keep saturated fats, trans fats, and sodium low.
- Choose food and beverages low in added sugars. Added sugars contribute to excessive caloric intake.

Module 23.15: Nutrition

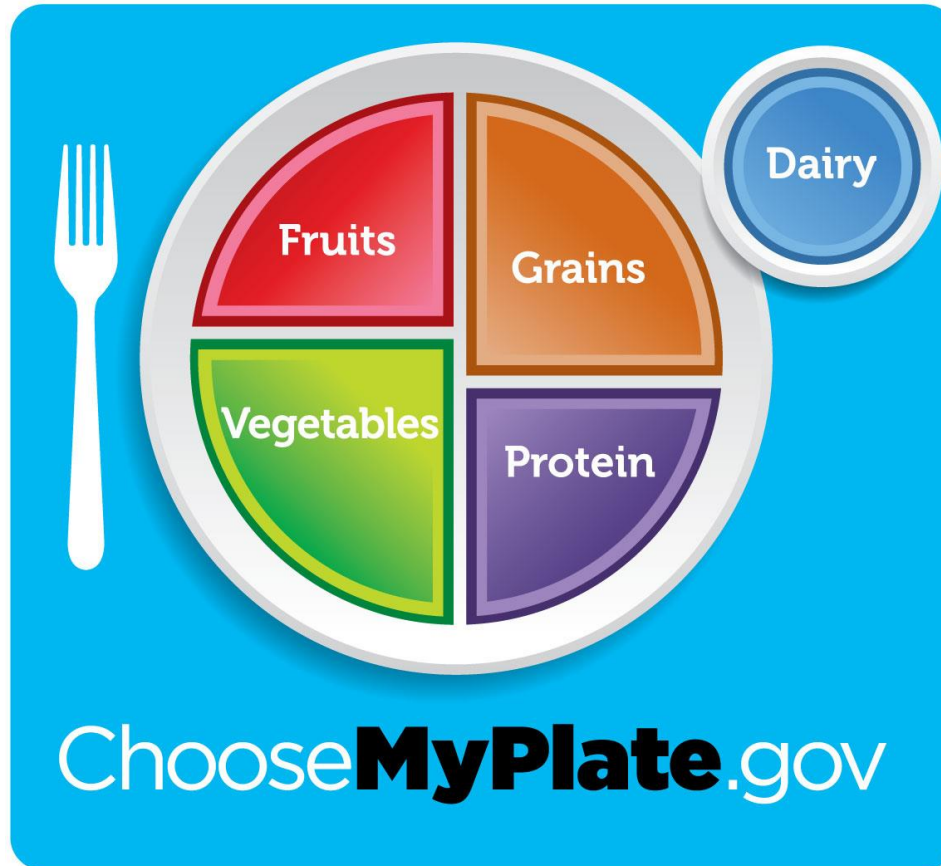
ChooseMyPlate.gov

- U.S. Department of Agriculture personalized eating plans based on current Dietary Guidelines for Americans
- Color-coded food groups indicate recommended proportions
 - Grains (orange)
 - Vegetables (green)
 - Fruits (red)
 - Dairy products (blue)
 - Proteins (purple)
 - Oils are not included in the MyPlate graphic and should be used sparingly

Find Your Balance between Food and Physical Activity

- Stay within your daily calorie needs.
- Adults should be physically active for at least 30 minutes most days of the week.
- About 60 minutes a day of physical activity may be needed to prevent weight gain.
- To sustain weight loss, at least 60 to 90 minutes a day of physical activity may be required.
- Children and teenagers should be physically active for 60 minutes most days.

Choose MyPlate.gov



GRAINS

Make half your grains whole

VEGETABLES

Vary your veggies

FRUITS

Focus on fruits

OILS

DAIRY

Get your calcium-rich foods

PROTEINS

Go lean with proteins

Module 23.15: Nutrition

Food energy content

- Common units are **calories**

- 1 calorie = energy to raise temperature of 1 g of water by 1°C

- **Kilocalorie** (kcal) or **Calorie** (Cal) is used

when referring to metabolism of the entire body

- 1 Cal = energy to raise temperature of 1 kg of water by 1°C

Energy Content of Some Food Types

Food Type	Serving	Cal
Breakfast bar	1 bar	368
Long-grain rice	1.5 cup	308
Bread, whole wheat	4 slices	277
Butter	0.5 tbsp	51
Beer, regular	12 fl oz	160
Cola, regular	12 fl oz	140

Module 23.15: Nutrition

Food energy content (continued)

- Energy yield of different nutrients varies
 - Carbohydrates: 4.18 Cal/g
 - Proteins: 4.32 Cal/g
 - Lipids: 9.46 Cal/g
- Average adult needs 2000–3000 Cal daily

Five Basic Food Groups and Their Effects on Health

Nutrient Group	Provides	Health Effects
Grains (recommended: at least half of total eaten should be whole grains)	Carbohydrates; vitamins E, thiamine, niacin, folate; calcium; phosphorus; iron; sodium; dietary fiber	Whole grains prevent rapid rise in blood glucose levels and consequent rapid rise in insulin levels
Vegetables (recommended: especially dark-green and orange vegetables)	Carbohydrates; vitamins A, C, E, folate; dietary fiber; potassium	Reduce risk of cardiovascular disease; protect against colon cancer (folate) and prostate cancer (lycopene in tomatoes)
Fruits (recommended: a variety of fruit each day)	Carbohydrates; vitamins A, C, E, folate; dietary fiber; potassium	Reduce risk of cardiovascular disease; protect against colon cancer (folate)
Dairy (recommended: low-fat or fat-free milk, yogurt, and cheese)	Complete proteins; fats; carbohydrates; calcium; potassium; magnesium; sodium; phosphorus; vitamins A, B ₁₂ , pantothenic acid, thiamine, riboflavin	Good source of calcium, which strengthens bones. Whole milk: High in calories, may cause weight gain; saturated fats associated with heart disease
Meat, Fish, Eggs, and Legumes (recommended: lean meats, fish, poultry, eggs, beans, peas, lentils)	Complete proteins; fats; calcium; potassium; phosphorus; iron; zinc; vitamins E, thiamine, B ₆	Fish and poultry lower risk of heart disease and colon cancer (compared to red meat). Consumption of up to one egg per day does not appear to increase incidence of heart disease; nuts and legumes improve blood cholesterol ratios, lower risk of heart disease and diabetes

Module 23.15: Nutrition

Complete/incomplete proteins

■ Complete proteins

- Provide all the essential amino acids in sufficient quantities
- From beef, fish, poultry, eggs, and dairy products



Module 23.15: Nutrition

Complete/incomplete proteins (continued)

■ Incomplete proteins

- Lack one or more essential amino acids
- Combinations of these can meet all amino acid requirements
 - Consideration for vegetarians and vegans



Module 23.15: Review

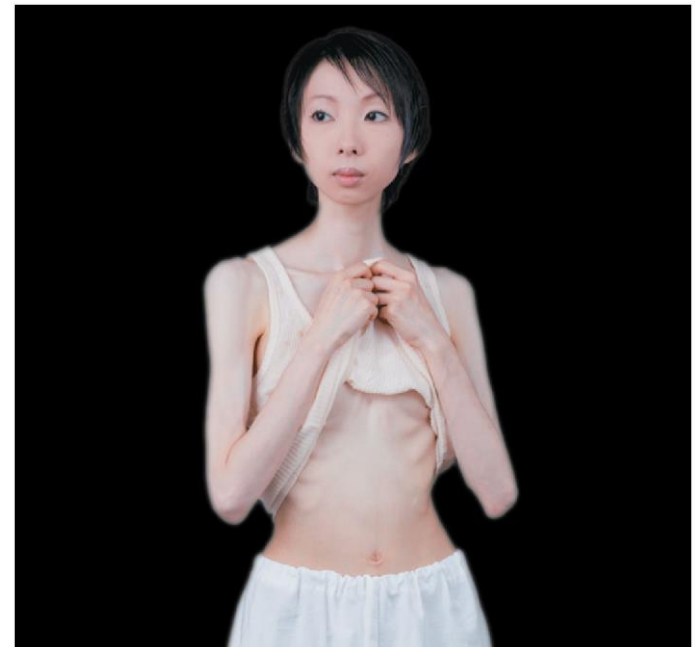
- A. Define *balanced diet*.
- B. Distinguish between a complete protein and an incomplete protein.
- C. Of these—carbohydrates, lipids, or proteins—which releases the greatest amount of energy per gram during catabolism?

Learning Outcome: Explain what constitutes a balanced diet and why such a diet is important.

Module 23.16: Clinical Module: Metabolic disorders may result from nutritional or biochemical problems

Eating disorders

- Psychological problems resulting in inadequate or excessive food consumption
- **Anorexia nervosa**
 - Self-induced starvation or lack/loss of appetite
 - Most common in adolescent Caucasian females
 - Weights commonly 30 percent below normal
 - Death rates in severe cases range from 10 to 15 percent



Module 23.16: Metabolic disorders

Eating disorders (continued)

■ Bulimia

- Condition in which individual “binges,” eating 20,000 calories or more, then induces vomiting
- Often uses laxatives and diuretics as well
- More common than anorexia nervosa
- Generally affects adolescent females

Module 23.16: Metabolic disorders

Eating disorders (continued)

■ Bulimia (continued)

- Health risks from
 1. Cumulative damage to the stomach, esophagus, oral cavity, and teeth from repeated exposure to stomach acids
 2. Electrolyte imbalances
 3. Edema
 4. Cardiac arrhythmias

Module 23.16: Metabolic disorders

Obesity

- Defined as a condition of being >20 percent over ideal weight
- Linked with serious health risks (diabetes, hypertension, hypercholesterolemia)



Module 23.16: Metabolic disorders

Obesity (continued)

- U.S. Centers for Disease Control (CDC) estimates obesity percentages at:
 - 35.7 percent of U.S. adults
 - ~17 percent of U.S. children
- Caused by food energy intake greater than energy usage



Module 23.16: Metabolic disorders

Obesity (continued)

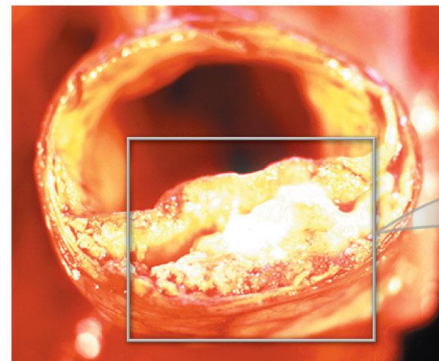
- Two major categories
 1. **Regulatory obesity**
 - Failure to regulate food intake
 - Most common form
 2. **Metabolic obesity**
 - Secondary to underlying malfunction in cell/tissue metabolism
 - Relatively rare



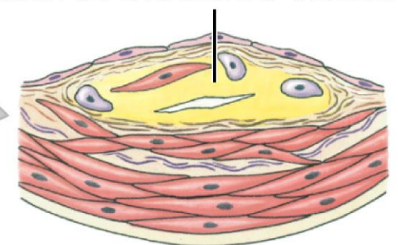
Module 23.16: Metabolic disorders

Elevated cholesterol levels

- Associated with development of atherosclerosis and coronary artery disease
- Recommended cholesterol intake <300 mg/day
- High LDL levels can lead to deposits in peripheral tissues such as blood vessels
- Low HDL levels (<35 mg/dL) also a problem
 - Excess cholesterol delivered to tissues is not easily returned to the liver



LDL cholesterol deposited in arterial walls, deforming the lumen of the blood vessel



Module 23.16: Metabolic disorders

Nutritional/metabolic disorders

- Phenylketonuria, or PKU

Nutritional/Metabolic Disorders

Phenylketonuria

Several inherited metabolic disorders result from an inability to produce specific enzymes involved in amino acid metabolism. People with **phenylketonuria** (fen-il-kē-tō-NŪ-rē-uh), or **PKU**, for example, cannot convert phenylalanine to tyrosine. This reaction is an essential step in the synthesis of norepinephrine, epinephrine, dopamine, and melanin. If PKU is not detected in infancy, central nervous system development is inhibited, and severe brain damage results. The condition is common enough that a warning is printed on the packaging of products, such as diet drinks, that contain phenylalanine.



Module 23.16: Metabolic disorders

Nutritional/metabolic disorders (continued)

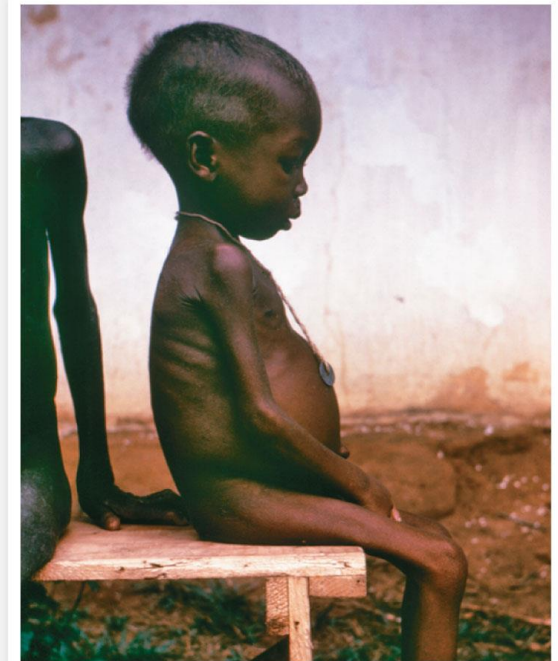
■ Protein deficiency disease

- Protein synthesis decreases throughout the body
- Plasma protein synthesis in the liver also affected
 - Reduced levels of plasma proteins lead to reduced plasma osmolarity
 - Fluid shifts out of capillaries and accumulates in the interstitial spaces (edema) and peritoneal cavity (ascites)

Module 23.16: Metabolic disorders

Nutritional/metabolic disorders (continued)

- **Protein deficiency disease (continued)**
 - *Example: kwashiorkor*
 - Occurs in children whose protein intake is inadequate, even if total caloric intake is sufficient
 - Complications include damage to the developing brain



Kwashiorkor

Module 23.16: Metabolic disorders

Nutritional/metabolic disorders (continued)

■ Ketoacidosis

- Acidification of blood due to **ketone body** production
 - Leads to **ketosis**
- Occurs when glucose supplies are limited
 - Fatty acid and amino acid catabolism in liver leads to acetyl-CoA production and generation of ketones
- In extreme cases, blood pH drops below 7.05
 - May cause coma, cardiac arrhythmias, and death

Module 23.16: Metabolic disorders

Nutritional/metabolic disorders (continued)

- Uncontrolled diabetes mellitus increases risk
 - No glucose available for the liver, so the liver responds as if starving, catabolizing proteins and lipids

Module 23.16: Metabolic disorders

Nutritional/metabolic disorders (continued)

■ Gout

- Condition involving insoluble uric acid crystals
- Purine bases of RNA catabolized into **uric acid**
 - Categorized as **nitrogenous waste** (contains nitrogen)
 - Normal uric acid levels 2.7–7.4 mg/dL
 - With higher concentrations, body fluids are saturated, and insoluble crystals form



Acute gouty arthritis of the great toe

Module 23.16: Metabolic disorders

Nutritional/metabolic disorders (continued)

■ Gout (continued)

- Crystals accumulate in joints, especially the great toe, causing **gouty arthritis**
 - Painful condition may persist for several days then disappear for days or years



Acute gouty arthritis of the great toe

Module 23.16: Review

- A. Identify and briefly define two eating disorders.
- B. Briefly describe phenylketonuria (PKU).
- C. Define *protein deficiency disease*, and cite an example.

Learning Outcome: Describe several metabolic disorders resulting from nutritional or biochemical problems.

Section 3: Energetics and Thermoregulation

Learning Outcomes

- 23.17 Explain energetics and the role of thermoregulation in maintaining homeostasis.
- 23.18 Describe the roles of the satiety center and the feeding center in the regulation of food intake.
- 23.19 Discuss the mechanisms involved in heat gain and heat loss.
- 23.20 Discuss the homeostatic mechanisms that maintain a constant body temperature.

Module 23.17: Energetics is the study of energy changes, and thermoregulation involves heat balance

Energetics

- Study of energy flow and energy conversion
- **Basal metabolic rate (BMR)**
 - Common benchmark for energetics studies
 - Defined as the minimum resting energy expenditure of awake, alert person

Module 23.17: Energetics and thermoregulation

BMR can be measured directly

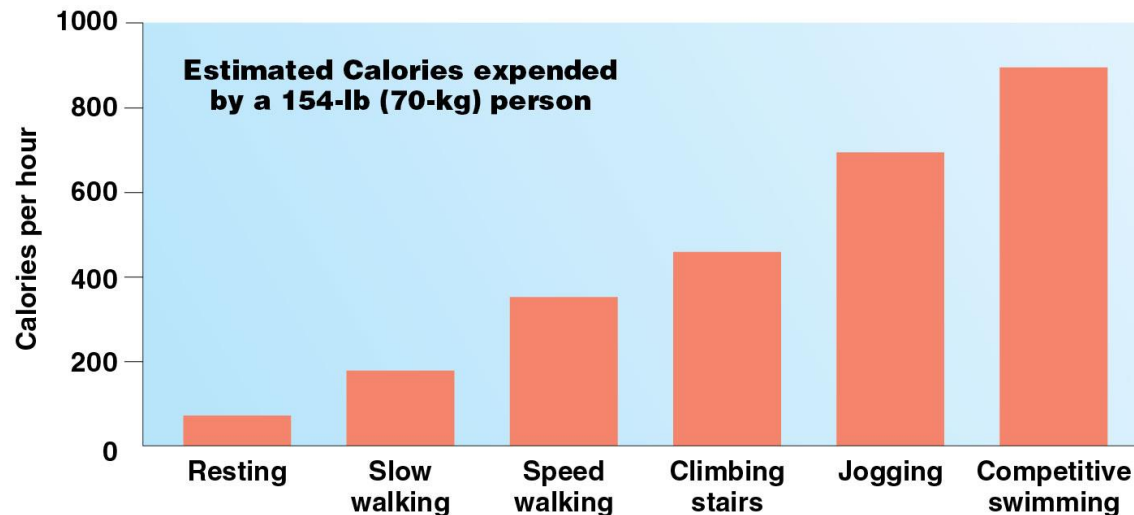
- Monitoring respiratory activity
- Assuming 4.825 Cal expended per liter of oxygen consumed



Module 23.17: Energetics and thermoregulation

Basal metabolic rate (continued)

- Average person has BMR of 70 Cal per hour (1680 Cal per day)
- Various factors can affect BMR
 - Size, weight, level of physical activity
- Food intake must be adequate to support activities



Module 23.17: Energetics and thermoregulation

Thermoregulation

- Homeostatic control of body temperature
- The body's metabolic activities generate heat
 - 40 percent of energy is used to form ATP
 - 60 percent is released as heat
 - Enzymes require specific range of temperature to function
 - Thermoregulation is required to maintain that range

Module 23.17: Review

- A. Define *energetics*.
- B. What is basal metabolic rate?
- C. Define *thermoregulation*.

Learning Outcome: Explain energetics and the role of thermoregulation in maintaining homeostasis.

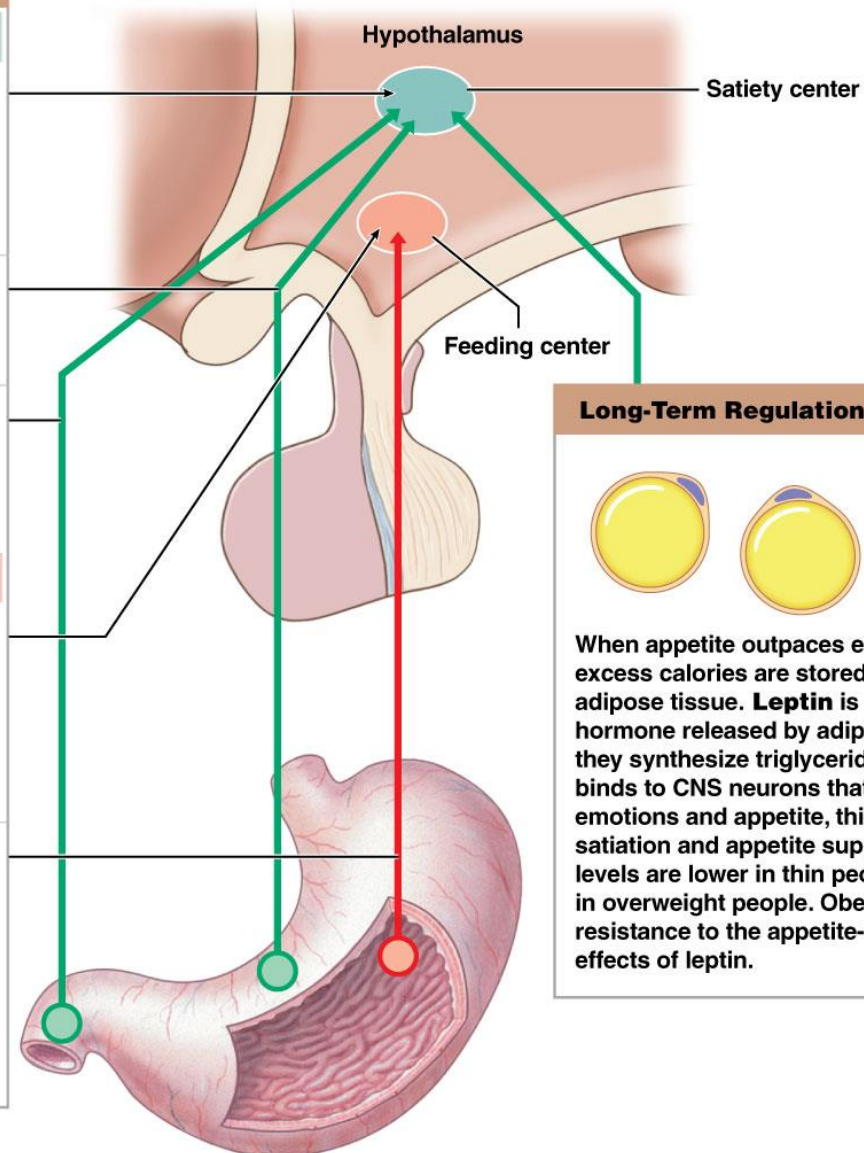
Module 23.18: The control of appetite is complex and involves both short-term and long-term mechanisms

Appetite control

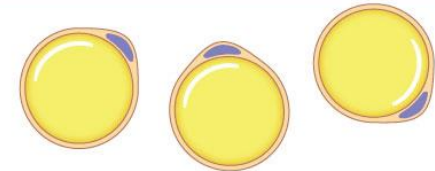
- Involves two areas of the hypothalamus with opposite effects (stimulating one inhibits the other)
 1. **Feeding center** (involved with hunger)
 2. **Satiety center** (involved with food satisfaction)

Control of appetite

Short-Term Regulation of Appetite
Stimulation of Satiety Center →
Elevated blood glucose levels depress appetite, and low blood glucose stimulates appetite. The likely mechanism is glucose entry stimulating the neurons of the satiety center.
Several hormones of the digestive tract, including CCK, suppress appetite during the absorptive state.
Stimulation of stretch receptors along the digestive tract, especially in the stomach, causes a sense of satiation and suppresses appetite.
Stimulation of Feeding Center →
Several neurotransmitters have been linked to appetite regulation. Neuropeptide Y (NPY) , for example, is a hypothalamic neurotransmitter that (among other effects) stimulates the feeding center and increases appetite.
The hormone ghrelin (GREL-in), secreted by the gastric mucosa, stimulates appetite. Ghrelin levels are high when the stomach is empty and decline as the stomach fills. Some research suggests that leptin plays a role in regulating ghrelin, showing that these “hunger hormones” are complex and warrant further study.



Long-Term Regulation of Appetite



When appetite outpaces energy usage, excess calories are stored as fat in adipose tissue. **Leptin** is a peptide hormone released by adipose tissues as they synthesize triglycerides. When leptin binds to CNS neurons that control emotions and appetite, this results in satiation and appetite suppression. Leptin levels are lower in thin people and higher in overweight people. Obese people have resistance to the appetite-suppressing effects of leptin.

Module 23.18: Control of appetite

Appetite control

- Affected by multiple factors, including social factors, psychological pressures, and dietary habits
- Regulation of appetite can occur on two levels
 1. Short-term regulation
 2. Long-term regulation

Module 23.18: Control of appetite

Short-term regulation of appetite

- Stimulation of satiety center
 - Elevated blood glucose levels
 - Hormones of digestive tract (such as CCK)
 - Stretching of digestive tract wall
- Stimulation of feeding center
 - Neurotransmitters
 - *Example: neuropeptide Y, or NPY, from hypothalamus*
 - **Ghrelin**
 - Hormone secreted by gastric mucosa when stomach is empty

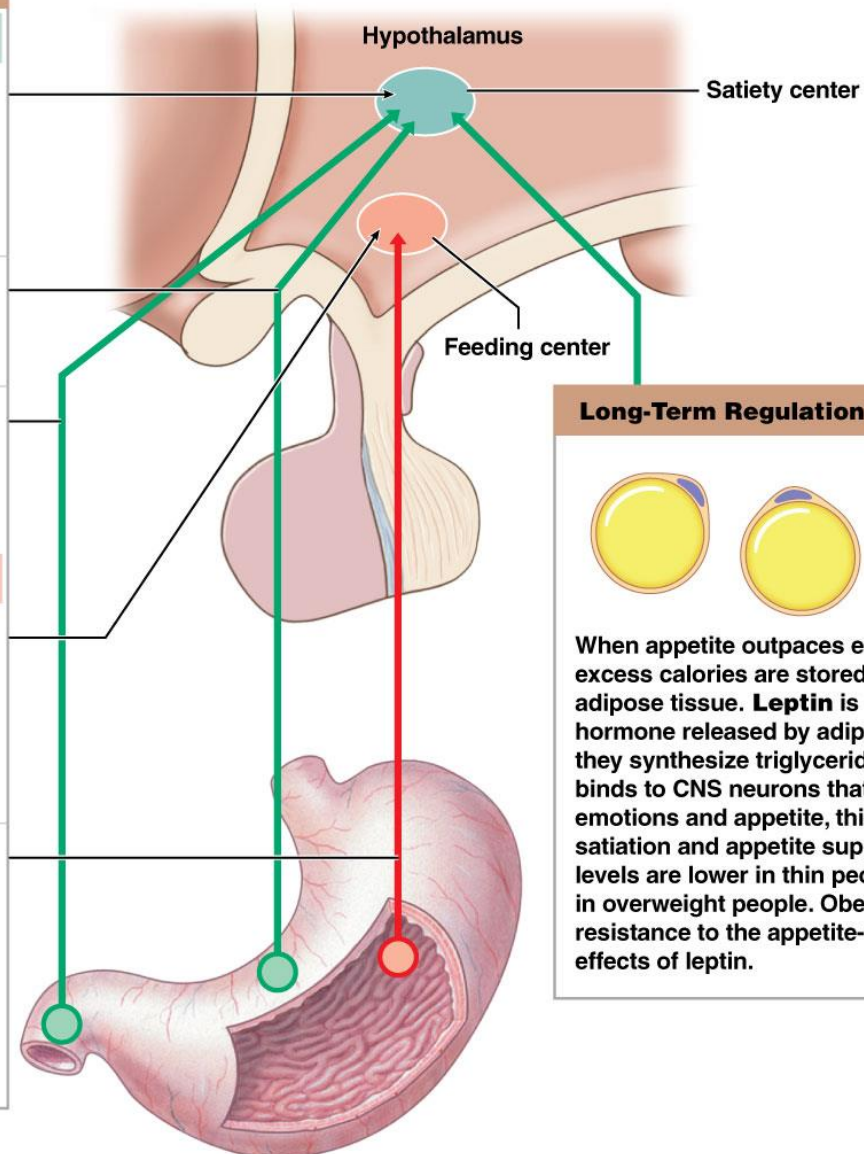
Module 23.18: Control of appetite

Long-term regulation of appetite

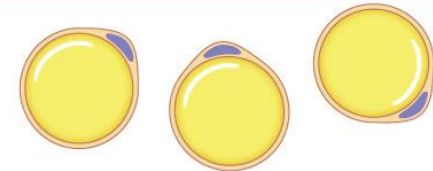
- Stimulation of the satiety center
 - **Leptin**
 - Peptide hormone secreted by adipocytes
 - Stimulates satiety center and suppresses appetite
 - Effects are gradual

Control of appetite

Short-Term Regulation of Appetite	
Stimulation of Satiety Center →	
Elevated blood glucose levels depress appetite, and low blood glucose stimulates appetite. The likely mechanism is glucose entry stimulating the neurons of the satiety center.	
Several hormones of the digestive tract, including CCK, suppress appetite during the absorptive state.	
Stimulation of stretch receptors along the digestive tract, especially in the stomach, causes a sense of satiety and suppresses appetite.	
Stimulation of Feeding Center →	
Several neurotransmitters have been linked to appetite regulation. Neuropeptide Y (NPY) , for example, is a hypothalamic neurotransmitter that (among other effects) stimulates the feeding center and increases appetite.	
The hormone ghrelin (GREL-in), secreted by the gastric mucosa, stimulates appetite. Ghrelin levels are high when the stomach is empty and decline as the stomach fills. Some research suggests that leptin plays a role in regulating ghrelin, showing that these "hunger hormones" are complex and warrant further study.	



Long-Term Regulation of Appetite



When appetite outpaces energy usage, excess calories are stored as fat in adipose tissue. **Leptin** is a peptide hormone released by adipose tissues as they synthesize triglycerides. When leptin binds to CNS neurons that control emotions and appetite, this results in satiation and appetite suppression. Leptin levels are lower in thin people and higher in overweight people. Obese people have resistance to the appetite-suppressing effects of leptin.

Module 23.18: Review

- A. Which hormone inhibits the satiety center and stimulates appetite in the short term?
- B. Describe leptin and its effect on appetite.
- C. How might a lack of neuropeptide Y in the hypothalamus affect the control of appetite?

Learning Outcome: Describe the roles of the satiety center and the feeding center in the regulation of food intake.

Module 23.19: To maintain a constant body temperature, heat gain and heat loss must be in balance

Mechanisms of heat transfer

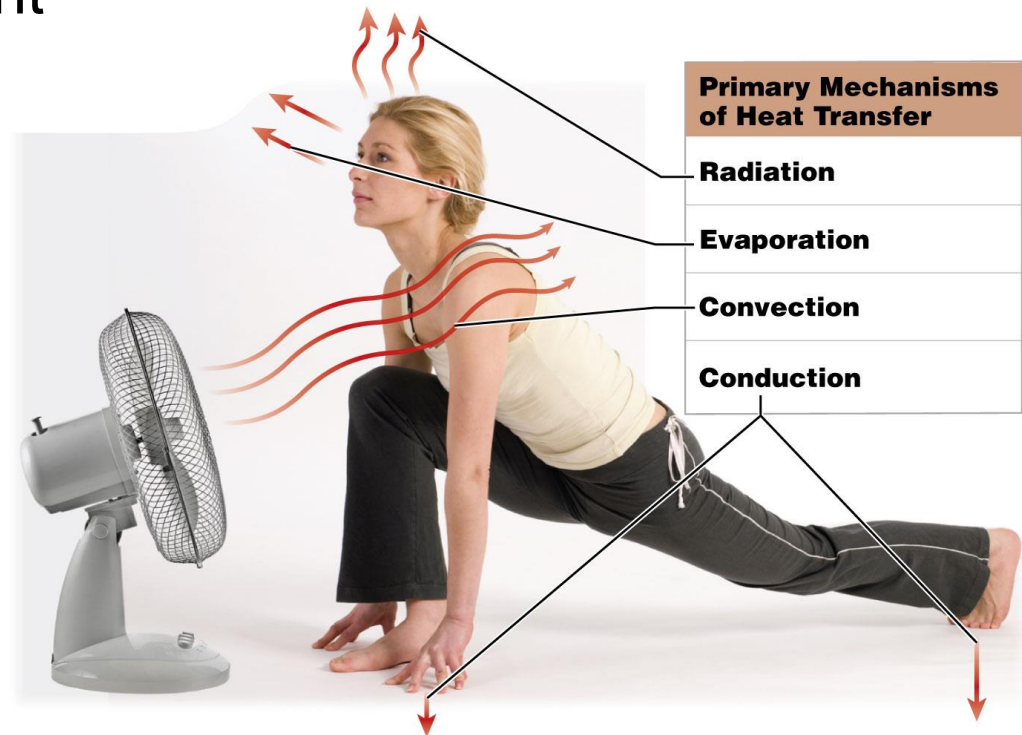
- Required to balance heat loss and heat production in order to maintain body temperature
- Four primary mechanisms

Module 23.19: Heat transfer

Mechanisms of heat transfer (continued)

1. Radiation

- Heat energy transfer as infrared radiation
- *Example:* the heat from the sun
- More than 50 percent of body heat loss indoors is via radiation

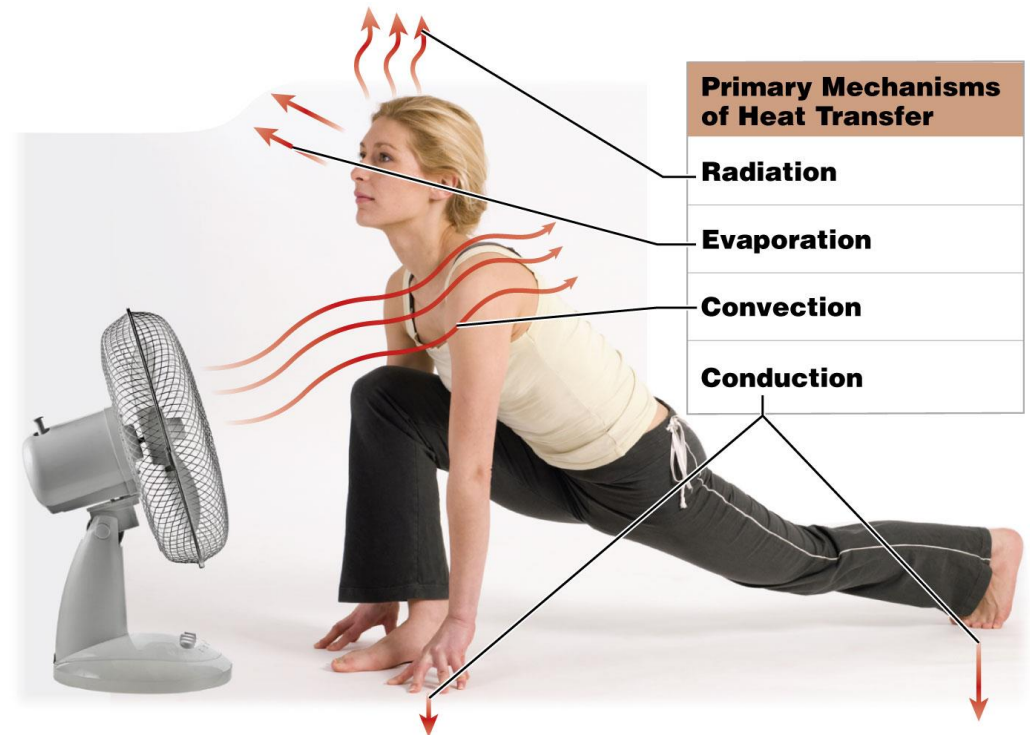


Module 23.19: Heat transfer

Mechanisms of heat transfer (continued)

2. Evaporation

- Water changing from liquid to vapor absorbs 0.58 Cal per gram of water
- Cools the surface of the skin



Module 23.19: Heat transfer

Mechanisms of heat transfer (continued)

2. Evaporation (continued)

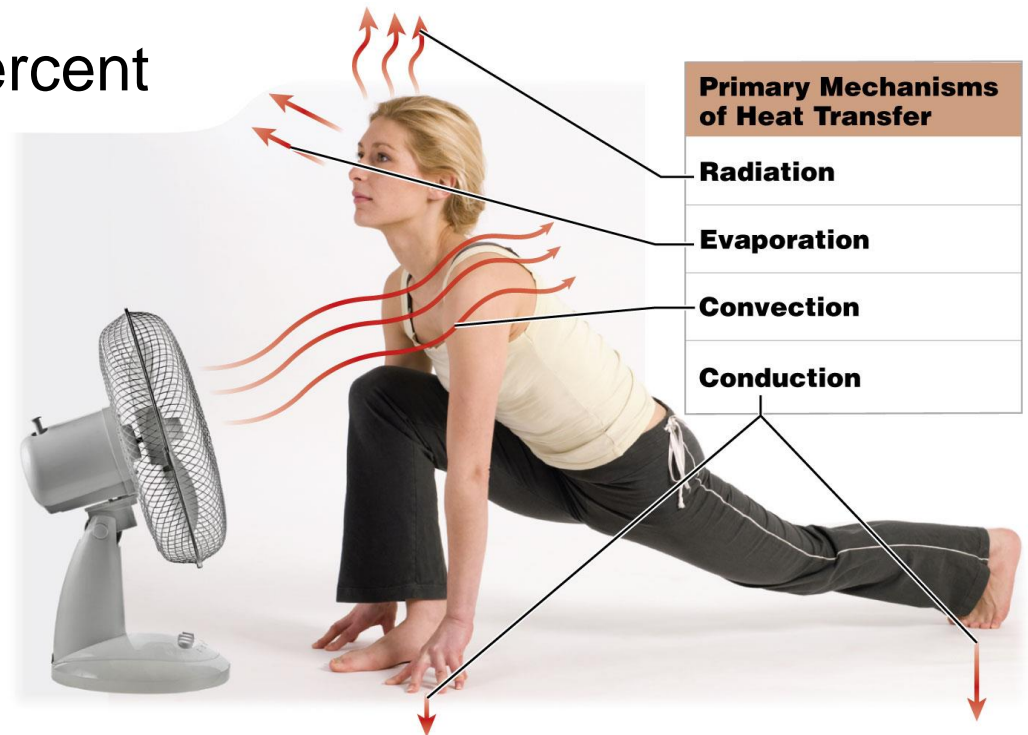
- **Insensible perspiration** (from alveoli and skin)
 - About 20–25 mL per hour (relatively constant)
 - Accounts for ~20 percent of body's average indoor heat loss
- **Sensible perspiration** (from sweat glands)
 - Can excrete up to 2–4 liters per hour

Module 23.19: Heat transfer

Mechanisms of heat transfer (continued)

3. Convection

- Result of heat loss due to air movement
- Warmer air rises away from the body, replaced by cooler air
- Accounts for ~15 percent of body's heat loss indoors

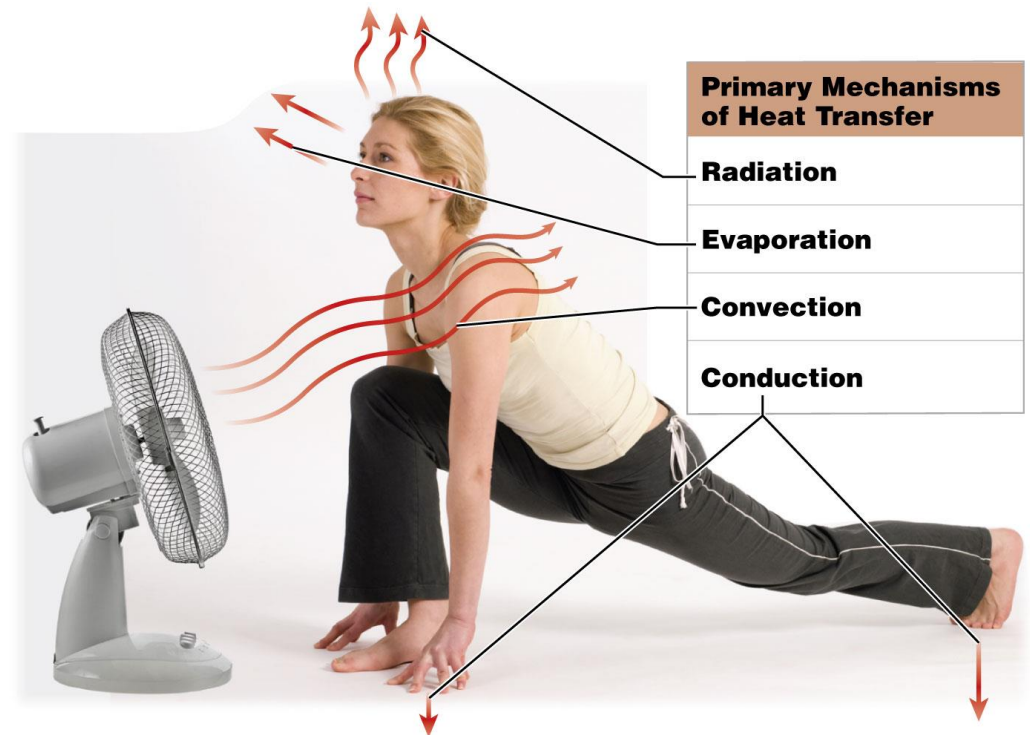


Module 23.19: Heat transfer

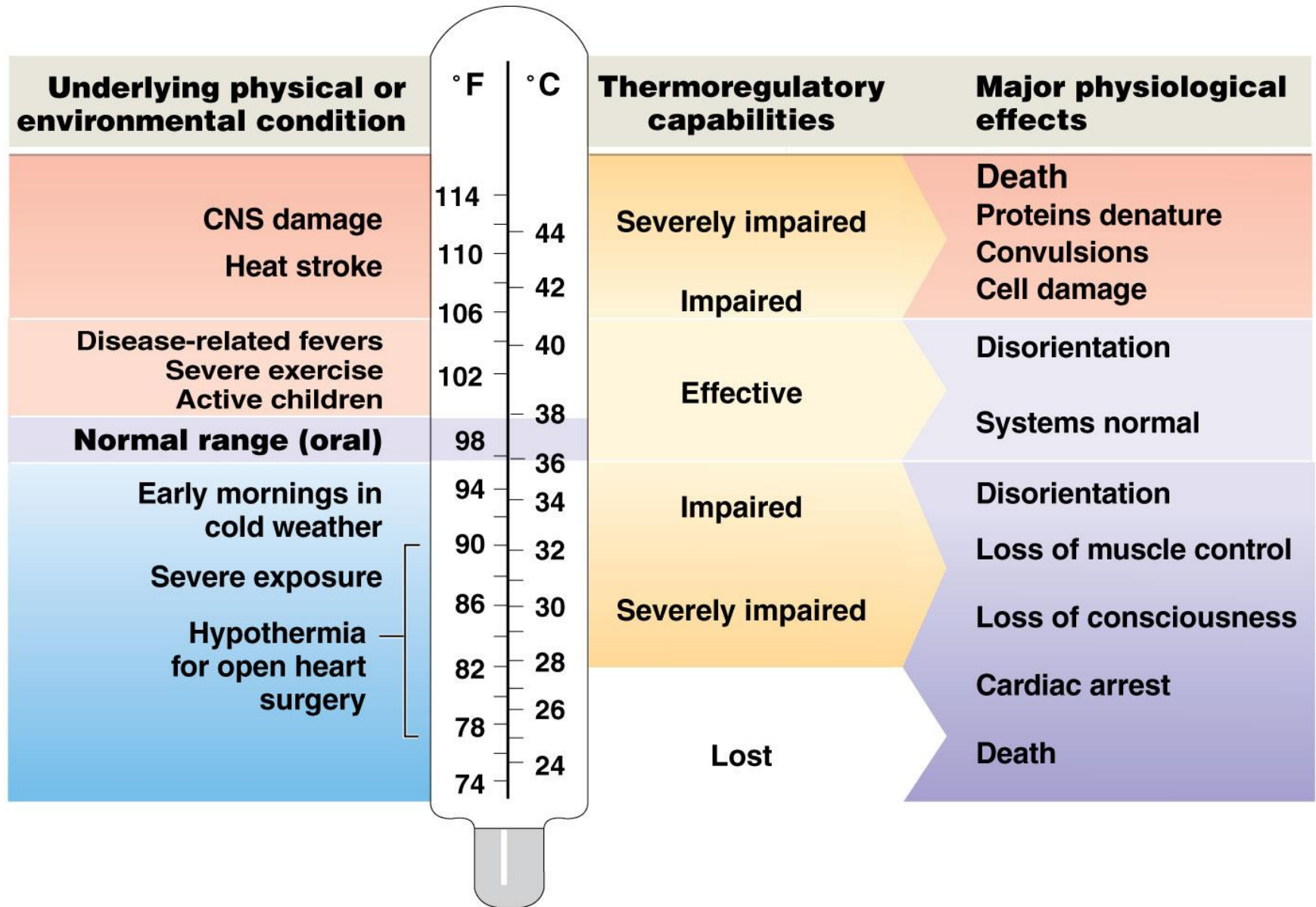
Mechanisms of heat transfer (continued)

4. Conduction

- Direct transfer of energy through physical contact
- Generally not an effective mechanism of gaining/losing heat



Effects of failure to control body temperature



Module 23.19: Review

- A. Define *insensible perspiration*.
- B. What heat transfer process accounts for about one-half of a person's heat loss when indoors?
- C. How is heat loss different between conduction and convection?

Learning Outcome: Discuss the mechanisms involved in heat gain and heat loss.

Module 23.20: Thermoregulatory centers in the hypothalamus adjust heat loss and heat gain

Thermoregulation

- Heat loss and heat gain involve many systems
- Coordinated by two centers in hypothalamus pre-optic area
 1. Heat-loss center
 2. Heat-gain center

Module 23.20: Thermoregulation

Responses to high body temperature

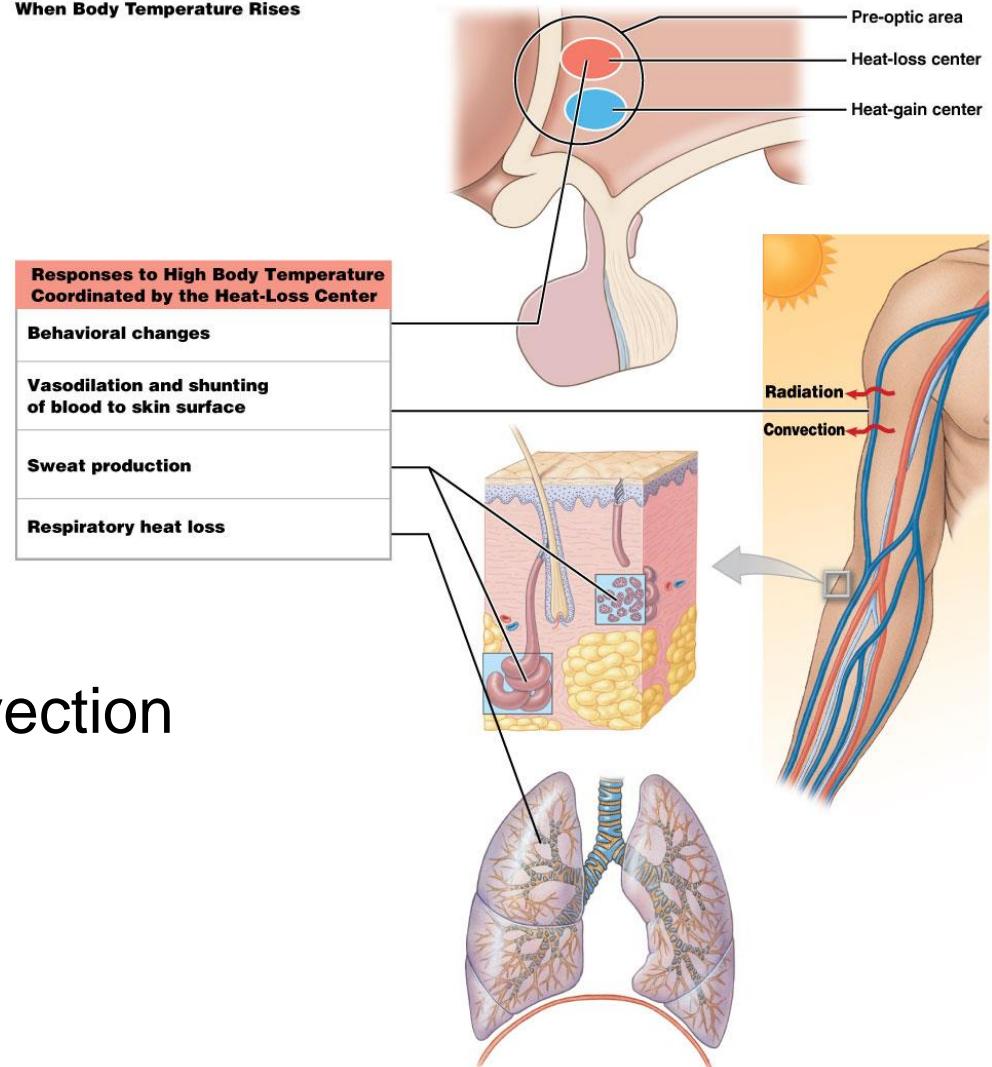
■ Behavioral changes

- Moving to shade, water, or other voluntary steps

■ Vasodilation and shunting of blood to skin surface

- Increases heat loss by radiation and convection

When Body Temperature Rises



Module 23.20: Thermoregulation

Responses to high body temperature (continued)

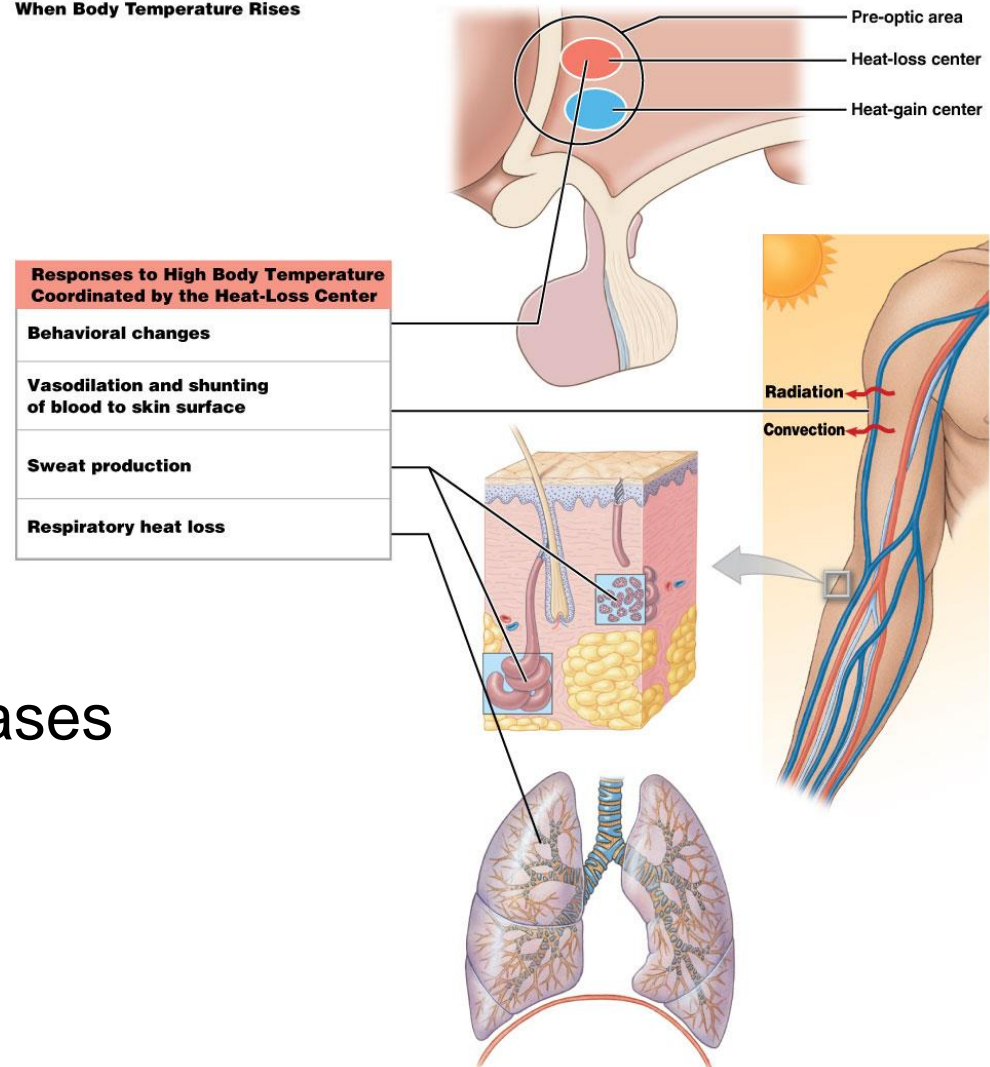
■ Sweat production

- Accelerates heat loss by evaporation

■ Respiratory heat loss

- Breathing more deeply and through an open mouth increases evaporative heat loss

When Body Temperature Rises

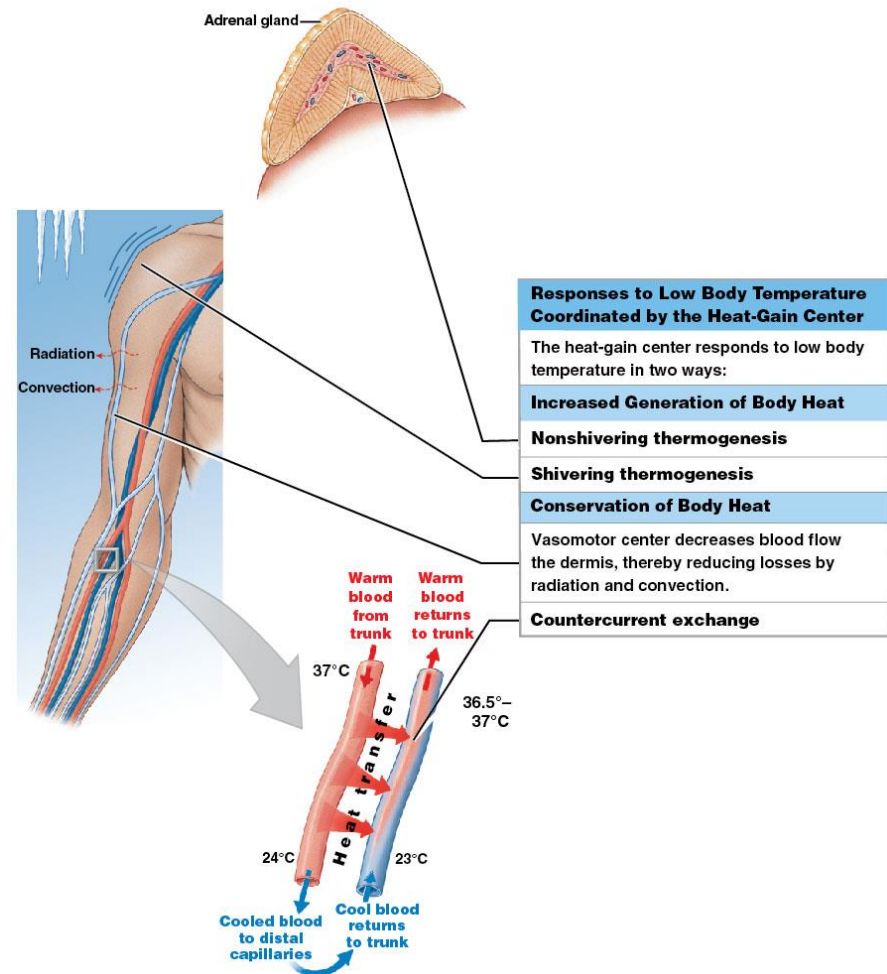


Module 23.20: Thermoregulation

Responses to low body temperature

- Increased generation of body heat
 - Nonshivering thermogenesis
 - Hormones (epinephrine, thyroid hormone) increase the metabolic activity of tissues

When Body Temperature Falls

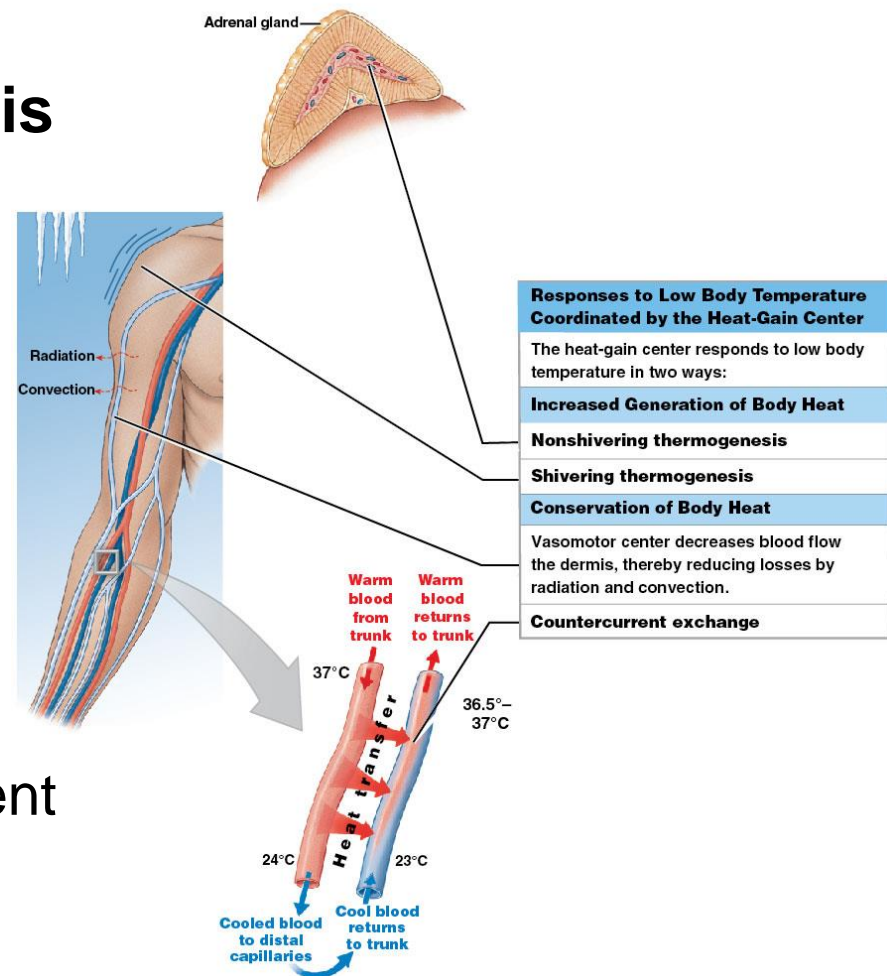


Module 23.20: Thermoregulation

Responses to low body temperature (continued)

- Increased generation of body heat (continued)
 - Shivering thermogenesis
 - Increase in muscle tone increases energy consumption
 - Increases to the point of involuntary contractions of skeletal muscles (shivering)
 - Can increase heat generation by 400 percent

When Body Temperature Falls



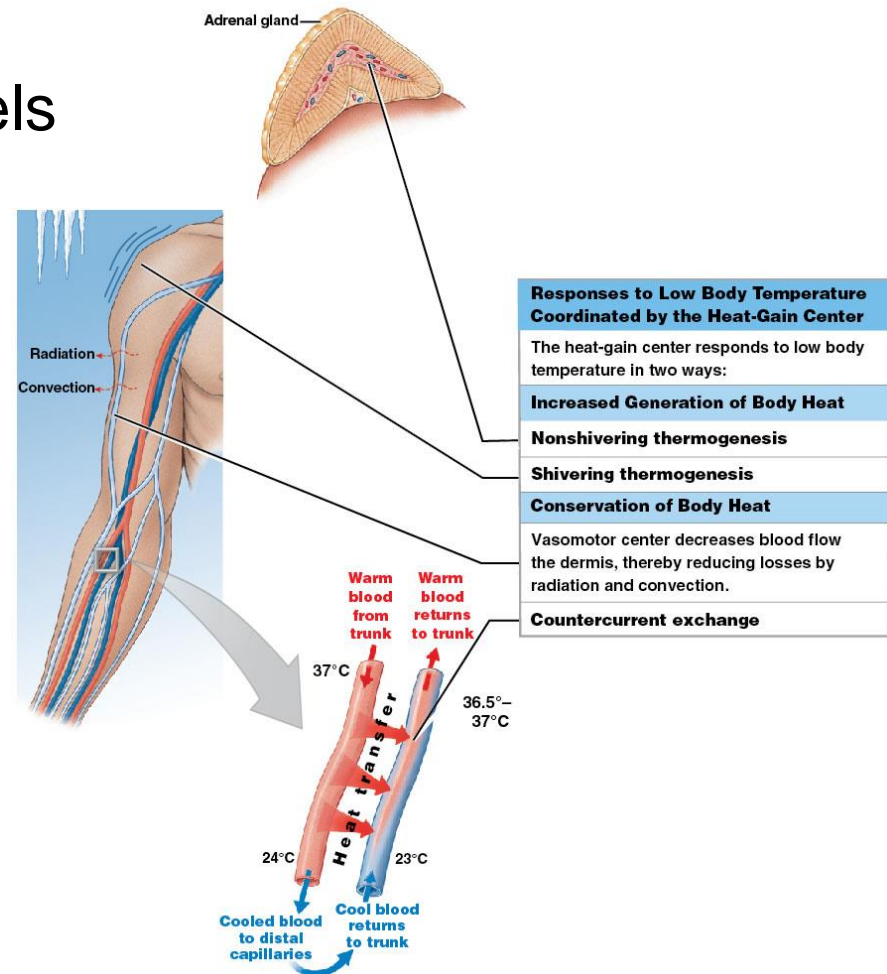
Module 23.20: Thermoregulation

Responses to low body temperature (continued)

■ Conservation of body heat

- Vasoconstriction of vessels near body surface
- Reduces heat loss by radiation and convection

When Body Temperature Falls



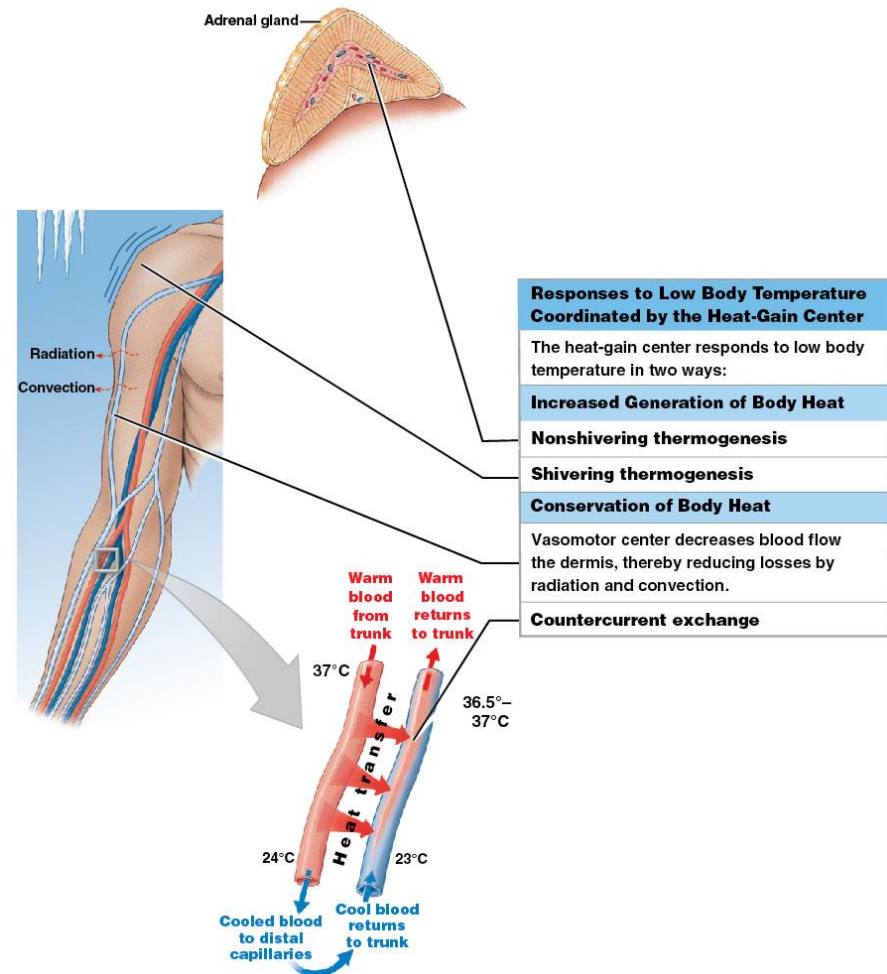
Module 23.20: Thermoregulation

Responses to low body temperature (continued)

■ Countercurrent exchange of heat

- Transfer of heat from deep arteries (bringing warmer blood from the body's core) to adjacent deep veins (bringing cooler blood from the periphery)
- Traps heat close to the body core and reduces heat loss

When Body Temperature Falls



Module 23.20: Review

- A. Predict the effect of peripheral vasodilation on a person's body temperature.
- B. Describe the role of nonshivering thermogenesis in regulating body temperature.
- C. Name the heat conservation mechanism that conducts heat from deep arteries to adjacent deep veins in the limbs.

Learning Outcome: Discuss the homeostatic mechanisms that maintain a constant body temperature.