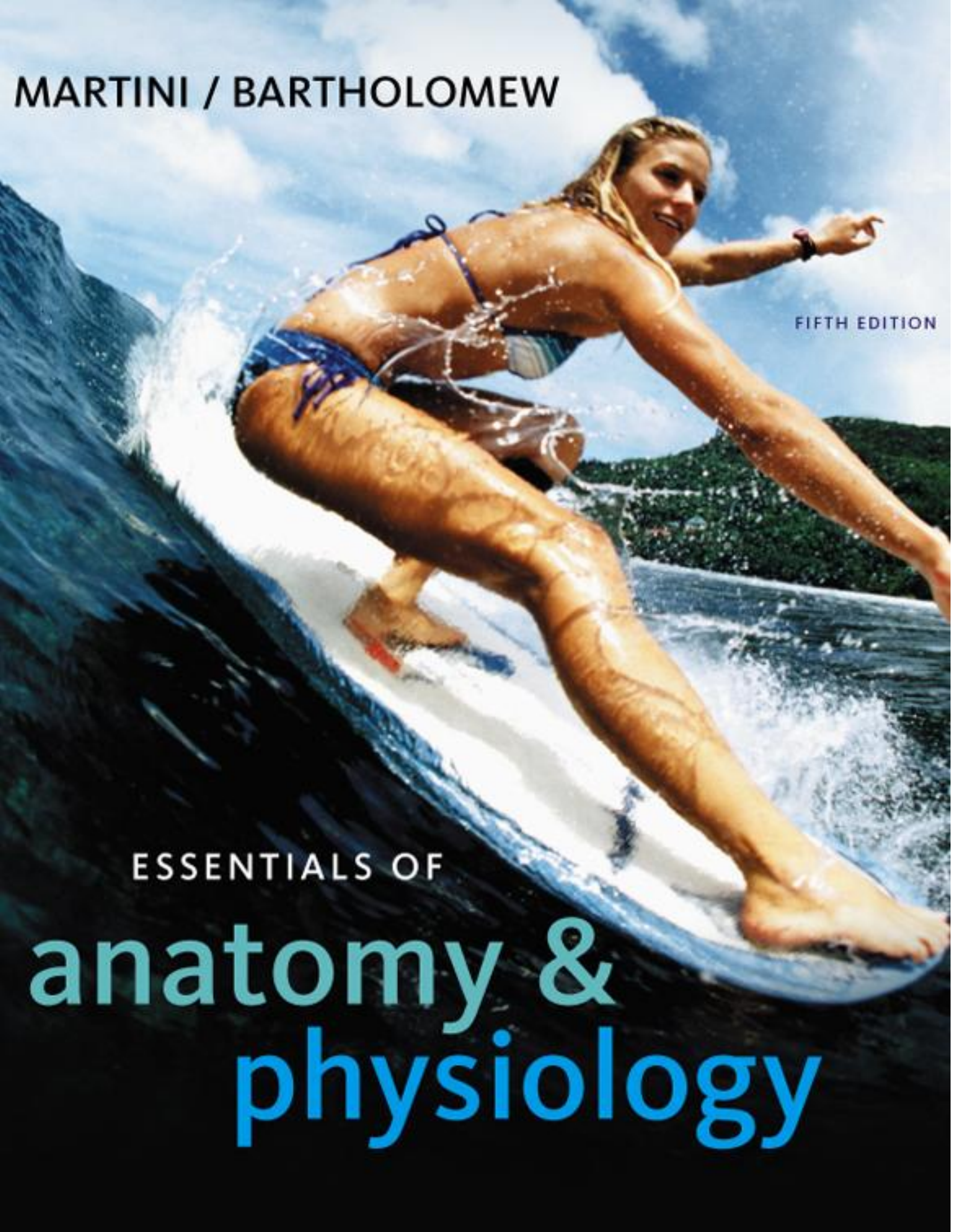

Chapter 17

Nutrition and Metabolism

PowerPoint® Lecture Slides
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Introduction to Nutrition and Metabolism

- Cells break down organic molecules to obtain energy
  - Used to generate ATP
- Most energy production takes place in mitochondria

Metabolism

- Body chemicals
  - Oxygen
  - Water
  - Nutrients:
    - Vitamins
    - Mineral ions
    - Organic substrates

Metabolism

- Body chemicals
  - Cardiovascular system:
    - Carries materials through body
  - Materials diffuse:
    - From bloodstream into cells

17-1 Metabolism refers to all the chemical reactions that occur in the body

Metabolism

- **Metabolism** refers to all chemical reactions in an organism
- Cellular Metabolism
  - Includes all chemical reactions within cells
  - Provides energy to maintain homeostasis and perform essential functions

Metabolism

- Essential Functions
  - Metabolic turnover:
    - Periodic replacement of cell's organic components
  - Growth and cell division
  - Special processes, such as secretion, contraction, and the propagation of action potentials

Cellular Metabolism

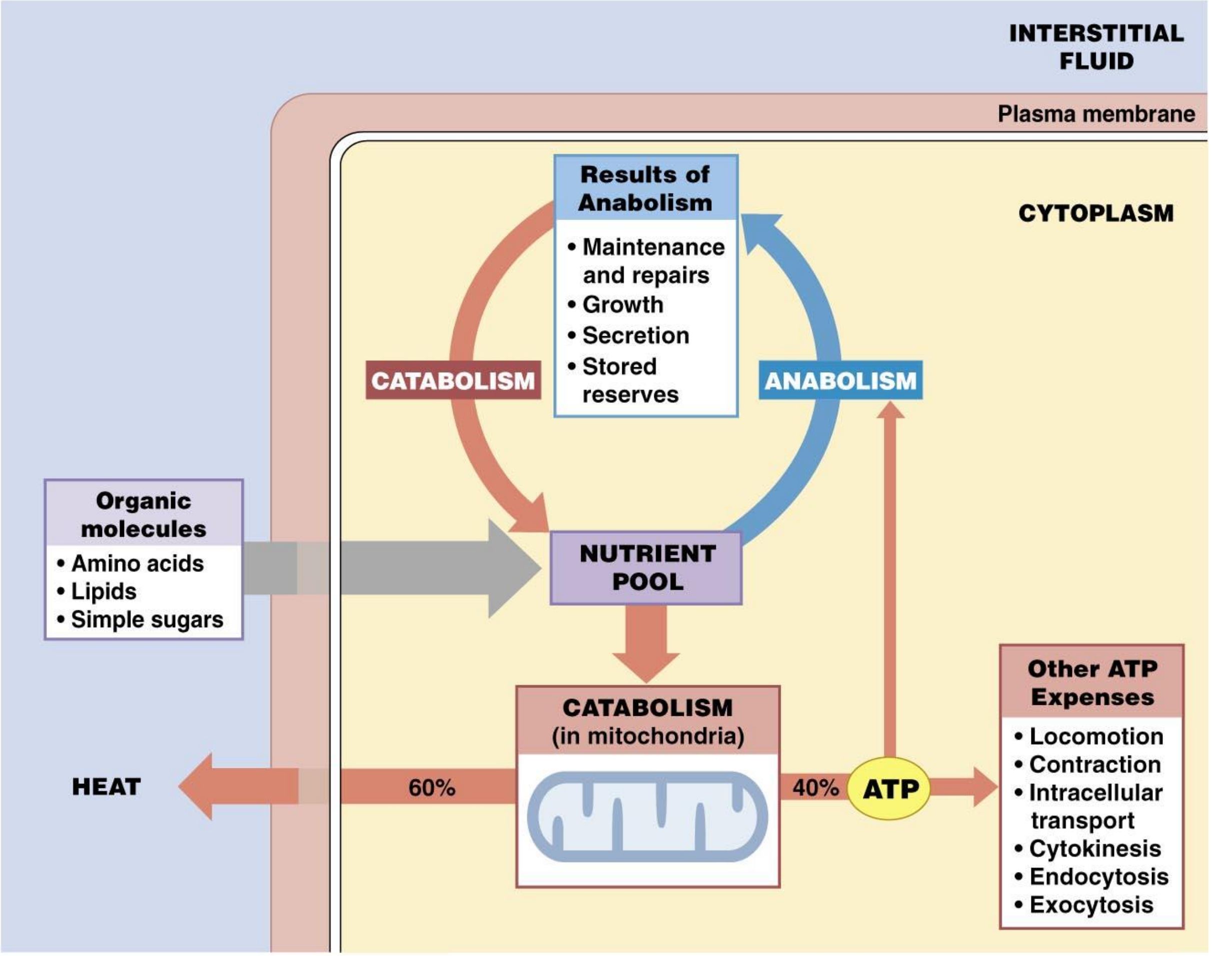


Figure 17-1

Metabolism

- The Nutrient Pool
  - Contains all organic building blocks the cell needs:
    - To provide energy
    - To create new cellular components
  - Is source of substrates for catabolism and anabolism

Metabolism

- **Catabolism**
  - Is the breakdown of organic substrates
  - Releases energy used to synthesize high-energy compounds (e.g., ATP)
- **Anabolism**
  - Is the synthesis of new organic molecules

Metabolism

- In energy terms
  - Anabolism is an “uphill” process that forms new chemical bonds

Metabolism

- Functions of Organic Compounds
  - Perform structural maintenance and repairs
  - Support growth
  - Produce secretions
  - Store nutrient reserves

Metabolism

- Organic Compounds
  - Glycogen:
    - Most abundant storage carbohydrate
    - A branched chain of glucose molecules
  - Triglycerides:
    - Most abundant storage lipids
    - Primarily of fatty acids
  - Proteins:
    - Most abundant organic components in body
    - Perform many vital cellular functions

Nutrient Use in Cellular Metabolism

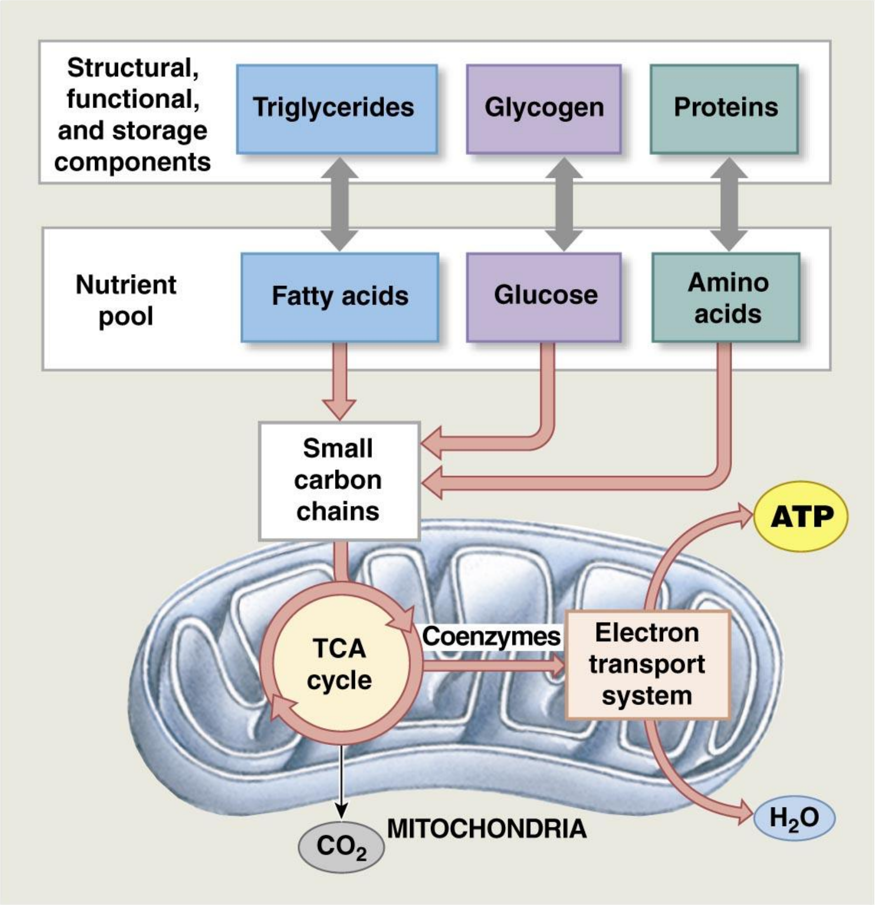


Figure 17-2

17-2 Carbohydrate metabolism involves glycolysis, ATP production, and gluconeogenesis

Carbohydrate Metabolism

- Generates ATP and other high-energy compounds by breaking down carbohydrates:

  glucose + oxygen → carbon dioxide + water

Glycolysis

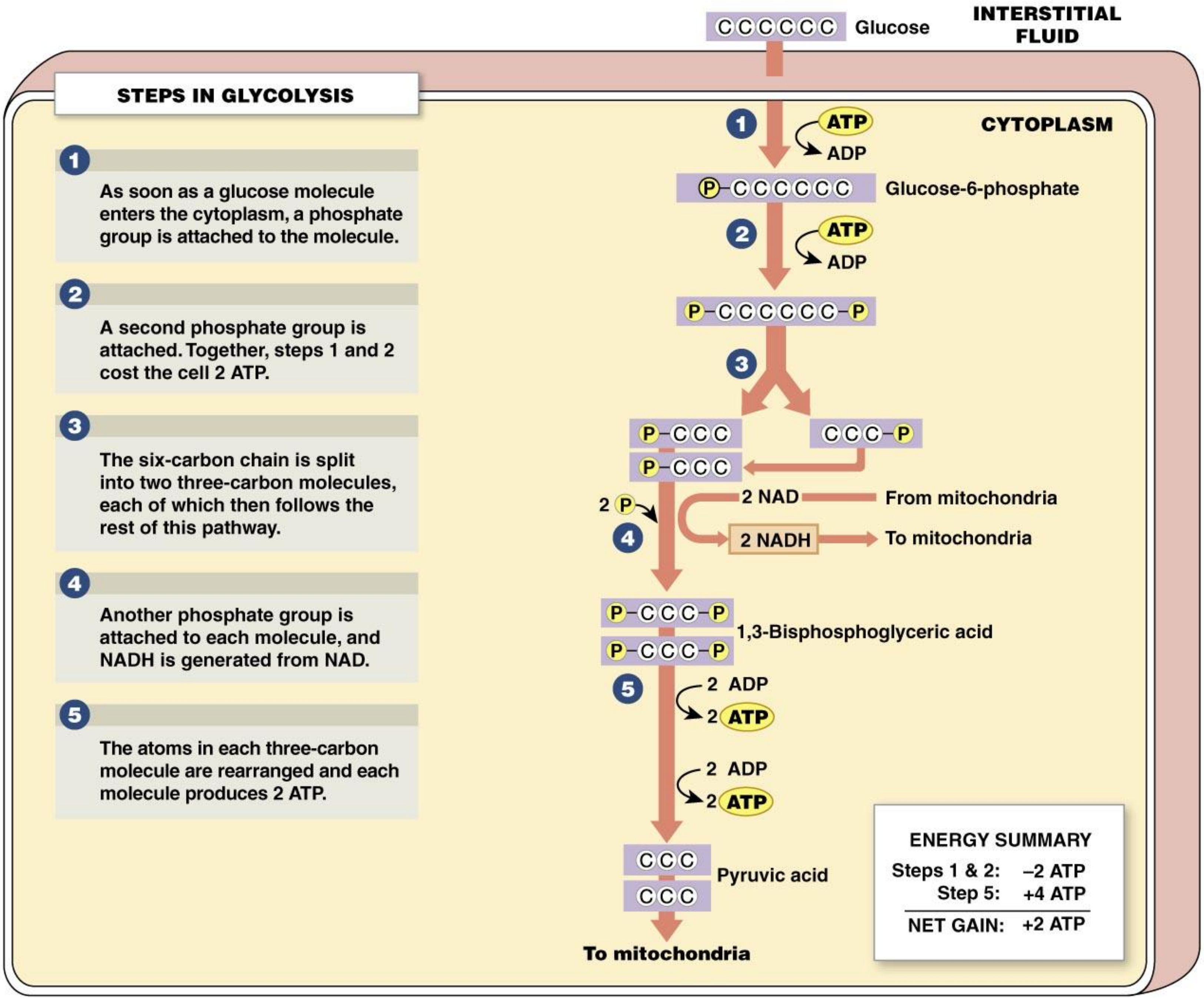
- Glucose Breakdown
  - Occurs in small steps:
    - Which release energy to convert ADP to ATP
  - One molecule of glucose nets 36 molecules of ATP
  - **Glycolysis:**
    - Breaks down glucose in cytosol into smaller molecules used by mitochondria
    - Does not require oxygen: anaerobic reaction
  - Aerobic Reactions:
    - Also called **aerobic metabolism** or cellular respiration
    - Occur in mitochondria, consume oxygen, and produce ATP

Glycolysis

- Glycolysis
  - – Breaks 6-carbon glucose
  - – Into two 3-carbon pyruvic acid
- Pyruvate
  - – Ionized form of **pyruvic acid**

Glycolysis

- Glycolysis Factors
  - Glucose molecules
  - Cytoplasmic enzymes
  - ATP and ADP
  - Inorganic phosphates
  - NAD (coenzyme)



C C C C C C Glucose
INTERSTITIAL FLUID
STEPS IN GLYCOLYSIS
1
As soon as a glucose molecule enters the cytoplasm, a phosphate group is attached to the molecule.
2
A second phosphate group is attached. Together, steps 1 and 2 cost the cell 2 ATP.
3
The six-carbon chain is split into two three-carbon molecules, each of which then follows the rest of this pathway.
4
Another phosphate group is attached to each molecule, and NADH is generated from NAD.
5
The atoms in each three-carbon molecule are rearranged and each molecule produces 2 ATP.
CYTOPLASM
1 ATP ADP
P C C C C C C Glucose-6-phosphate
2 ATP ADP
P C C C C C C P
3
P C C C
C C C P
P C C C
2 NAD From mitochondria
2 P
4
2 NADH To mitochondria
P C C C P
P C C C P
1,3-Bisphosphoglyceric acid
5
2 ADP
2 ATP
2 ADP
2 ATP
C C C
C C C
Pyruvic acid
To mitochondria
ENERGY SUMMARY
Steps 1 & 2: –2 ATP
Step 5: +4 ATP
NET GAIN: +2 ATP

Figure

17-3

Energy Production Within Mitochondria

- If oxygen supplies are adequate, mitochondria absorb and break down pyruvic acid molecules:
  - H atoms of pyruvic acid are removed by coenzymes and are a primary source of energy gain
  - C and O atoms are removed and released as CO_2 in the process of **decarboxylation**

Energy Production Within Mitochondria

- **The TCA Cycle** (citric acid cycle)
  - The function of the citric acid cycle is:
    - To remove hydrogen atoms from organic molecules and transfer them to coenzymes
  - In the mitochondrion:
    - Pyruvic acid reacts with NAD and **coenzyme A (CoA)**
    - Producing 1 CO_2, 1 NADH, 1 acetyl-CoA
  - **Acetyl group** transfers:
    - From **acetyl-CoA** to oxaloacetic acid
    - Produces **citric acid**

Energy Production Within Mitochondria

- The TCA Cycle
  - CoA is released to bind another acetyl group
  - One TCA cycle removes two carbon atoms:
    - Regenerating 4-carbon chain
  - Several steps involve more than one reaction or enzyme
  - H_2O molecules are tied up in two steps
  - CO_2 is a waste product
  - The product of one TCA cycle is:
    - One molecule of **ATP**

PLAY The TCA Cycle

Energy Production Within Mitochondria

- Summary: The TCA Cycle

$$CH_3CO - CoA + 3NAD + FAD + GDP + P_i + 2\ H_2O \rightarrow$$
$$CoA + 2\ CO_2 + 3NADH + FADH_2 + 2\ H^+ + ATP$$

The TCA Cycle

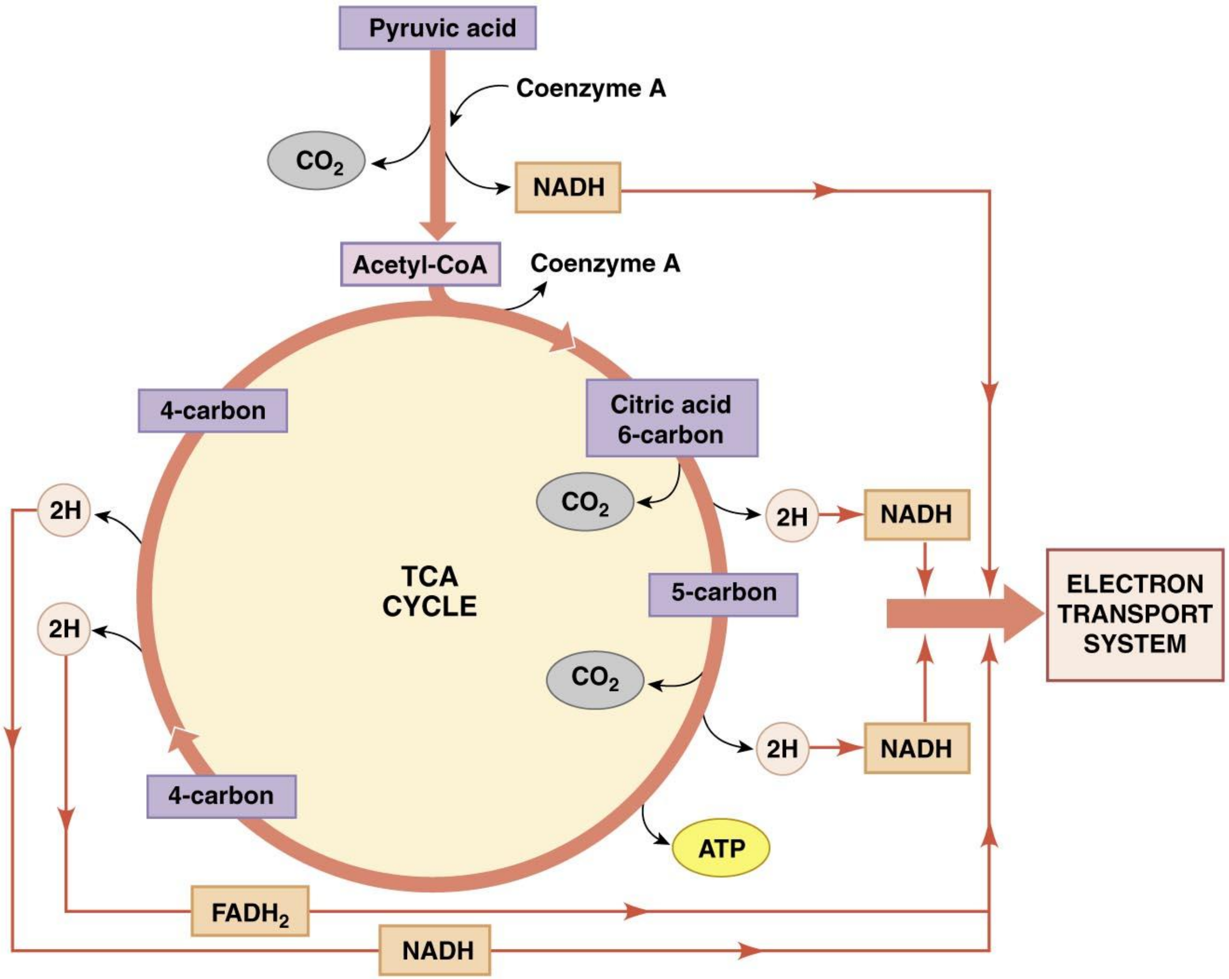


Figure 17-4

Energy Production Within Mitochondria

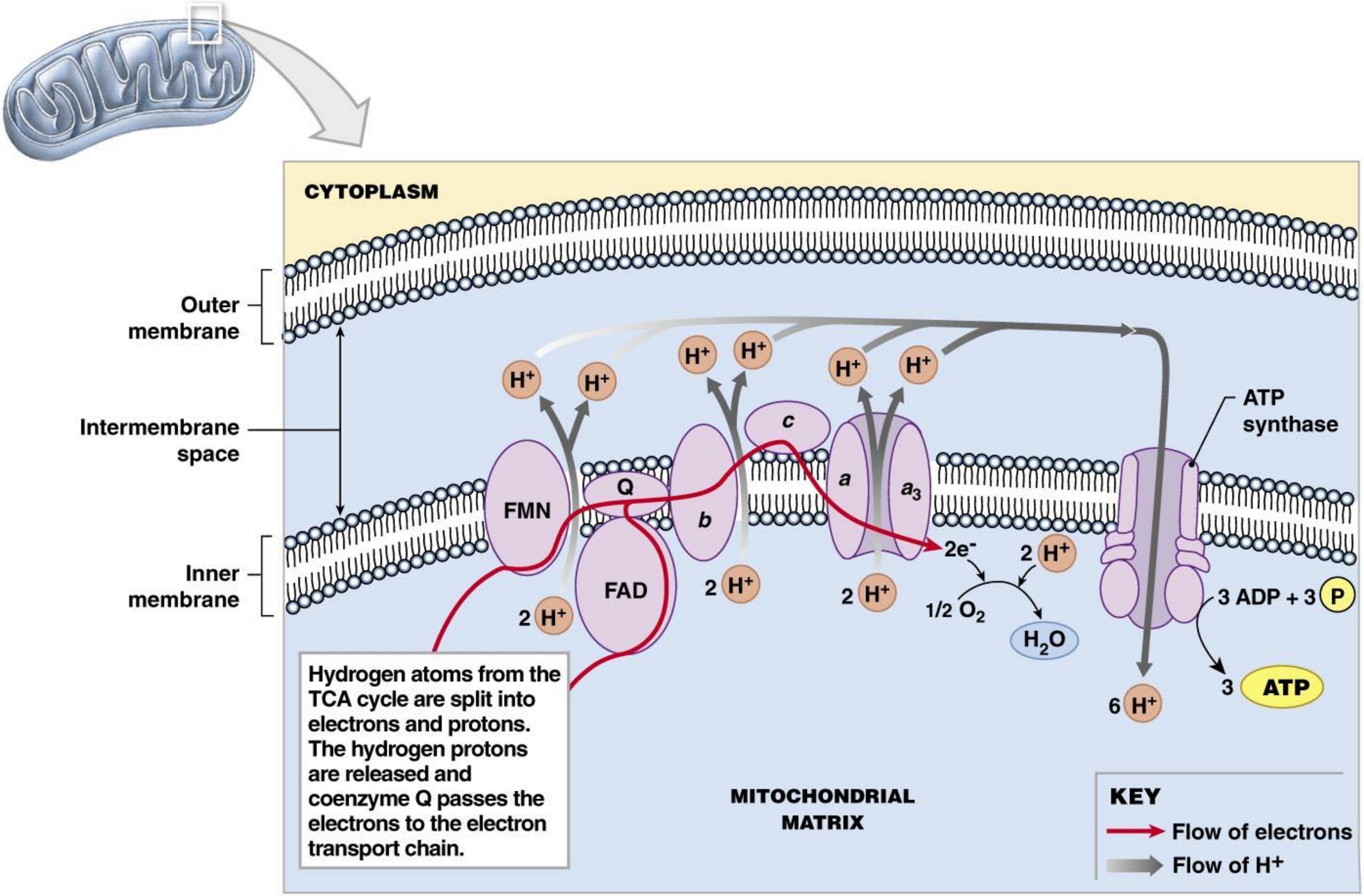
- Oxidative Phosphorylation and the ETS
  - Is the generation of ATP:
    - Within mitochondria
    - In a reaction requiring coenzymes and oxygen
  - Produces more than 90% of ATP used by body
  - Results in $2\ H_2 + O_2 \rightarrow 2\ H_2O$

Energy Production Within Mitochondria

- The Electron Transport System (ETS)
  - Is the key reaction in **oxidative phosphorylation**
  - Is in inner mitochondrial membrane
  - Electrons carry chemical energy:
    - Within a series of integral and peripheral proteins

Energy Production Within Mitochondria

- The Electron Transport System (ETS)
  - Also called respiratory chain
  - Is a sequence of proteins (**cytochromes**):
    - Protein:
      - embedded in inner membrane of mitochondrion
      - surrounds pigment complex
    - Pigment complex:
      - contains a metal ion (iron or copper)



CYTOPLASM
Outer membrane
Intermembrane space
Inner membrane
H+
FMN
Q
FAD
b
c
a
a3
2 H+
2e-
1/2 O2
H2O
ATP synthase
3 ADP + 3 P
3 ATP
6 H+
Hydrogen atoms from the TCA cycle are split into electrons and protons. The hydrogen protons are released and coenzyme Q passes the electrons to the electron transport chain.
MITOCHONDRIAL MATRIX
KEY
Flow of electrons
Flow of H+

Figure 17-5

Energy Yield of Glycolysis and Cellular Respiration

- For most cells, reaction pathway
  - Begins with glucose
  - Ends with carbon dioxide and water
  - Is main method of generating ATP

Energy Yield of Glycolysis and Cellular Respiration

- Summary: ATP Production
  - For one glucose molecule processed, cell gains 36 molecules of ATP:
    - 2 from glycolysis
    - 4 from NADH generated in glycolysis
    - 2 from TCA cycle (through GTP)
    - 28 from ETS

Alternative Catabolic Pathways

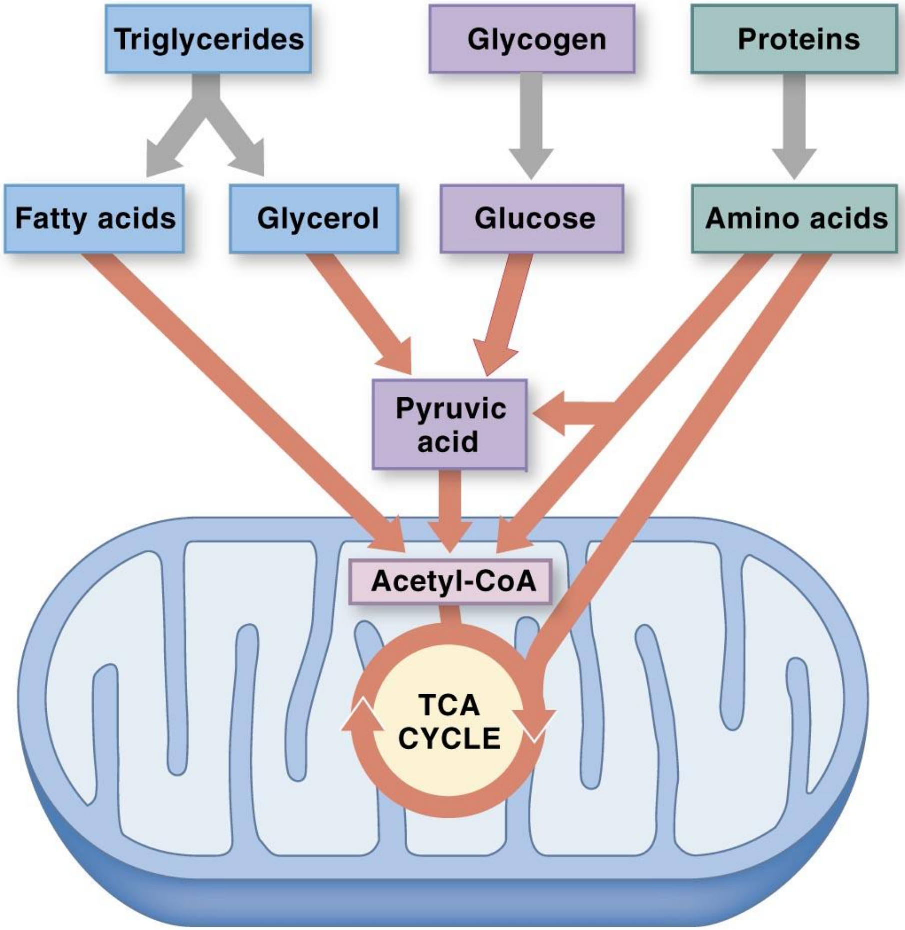


Figure 17-6

Gluconeogenesis

- Is the synthesis of glucose from noncarbohydrate precursors
  - Lactic acid
  - Glycerol
  - Amino acids
- Stores glucose as glycogen in liver and skeletal muscle

Carbohydrate Metabolism

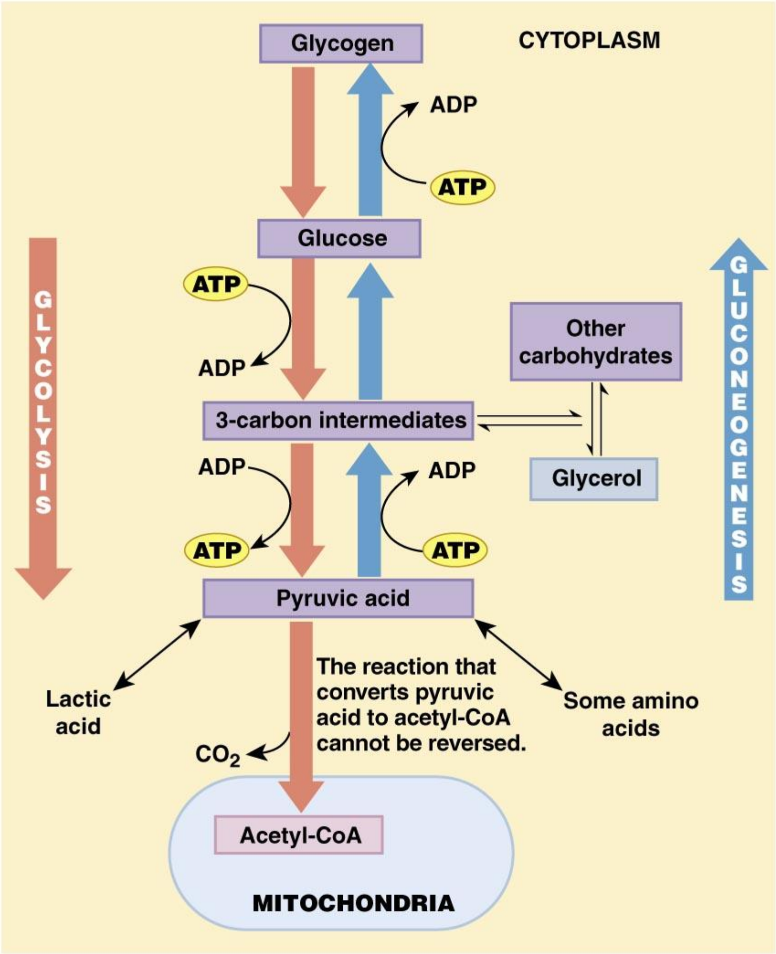


Figure 17-7

17-3 Lipid metabolism involves lipolysis, beta-oxidation, and the transport and distribution of lipids as lipoproteins and free fatty acids

Lipid Metabolism

- Lipid molecules contain carbon, hydrogen, and oxygen
  - In different proportions than carbohydrates
- Triglycerides are the most abundant lipid in the body

Lipid Metabolism

- Lipid Catabolism (also called **lipolysis**)
  - Breaks lipids down into pieces that can be:
    - Converted to pyruvic acid
    - Channeled directly into TCA cycle
  - Hydrolysis splits triglyceride into component parts:
    - One molecule of glycerol
    - Three fatty acid molecules

Lipid Metabolism

- Lipid Catabolism
  - Enzymes in cytosol convert glycerol to pyruvic acid:
    - Pyruvic acid enters TCA cycle
  - Different enzymes convert fatty acids to acetyl-CoA (**beta-oxidation**)

Lipid Metabolism

- Beta-Oxidation
  - A series of reactions
  - Breaks fatty acid molecules into 2-carbon fragments
  - Occurs inside mitochondria
  - Each step:
    - Generates molecules of acetyl-CoA and NADH
    - Leaves a shorter carbon chain bound to coenzyme A

Lipids and Energy Production

- For each 2-carbon fragment removed from fatty acid, cell gains
  - 2 ATP from acetyl-CoA in TCA cycle
  - 5 ATP from NADH
- Cell can gain 144 ATP molecules from breakdown of one 18-carbon fatty acid molecule
- Fatty acid breakdown yields about 1.5 times the energy of glucose breakdown

Lipid Synthesis

- Can use almost any organic substrate
  - Because lipids, amino acids, and carbohydrates can be converted to acetyl-CoA
- Glycerol
  - Is synthesized from dihydroxyacetone phosphate (intermediate product of glycolysis)
- Other Lipids
  - Nonessential fatty acids and steroids are examples
  - Are synthesized from acetyl-CoA

Lipid Transport and Distribution

- Cells require lipids
  - To maintain plasma membranes
- Steroid hormones must reach target cells in many different tissues

Lipid Transport and Distribution

- **Lipoproteins**
  - Are lipid–protein complexes
  - Contain large insoluble glycerides and cholesterol
  - Five classes of lipoproteins:
    - Chylomicrons
    - Very low-density lipoproteins (VLDLs)
    - Intermediate-density lipoproteins (IDLs)
    - Low-density lipoproteins (LDLs)
    - High-density lipoproteins (HDLs)

Lipid Synthesis

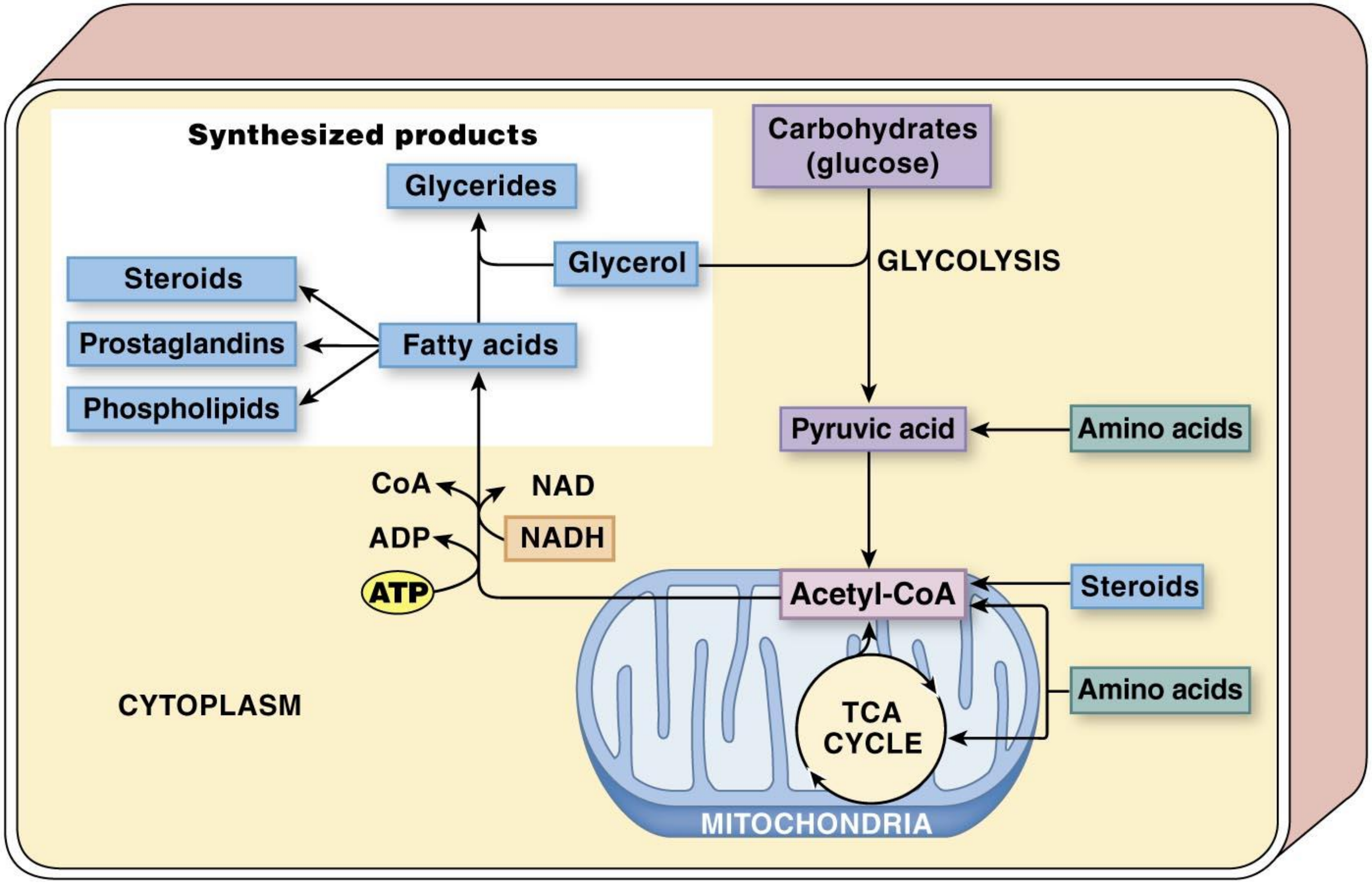


Figure 17-8

17-4 Protein catabolism involves transamination and deamination, whereas protein synthesis involves amination and transamination

Protein Metabolism

- The body synthesizes 100,000 to 140,000 proteins
  - Each with different form, function, and structure
- All proteins are built from the 20 amino acids
- Cellular proteins are recycled in cytosol
  - Peptide bonds are broken
  - Free amino acids are used in new proteins

Protein Metabolism

- If other energy sources are inadequate
  - Mitochondria generate ATP by breaking down amino acids in TCA cycle
- Not all amino acids enter cycle at same point, so ATP benefits vary

Amino Acid Catabolism

- Removal of amino group by **transamination** or **deamination**
  - Requires coenzyme derivative of vitamin B_6 (pyridoxine)

Protein Metabolism

- Transamination
  - Attaches amino group of amino acid:
    - To **keto acid**
  - Converts keto acid into amino acid:
    - That leaves mitochondrion and enters cytosol
    - Available for protein synthesis

Protein Metabolism

- Deamination
  - Prepares amino acid for breakdown in TCA cycle
  - Removes amino group and hydrogen atom:
    - Reaction generates **ammonium ion**

Protein Metabolism

- Proteins and ATP Production
  - When glucose and lipid reserves are inadequate, liver cells:
    - Break down internal proteins
    - Absorb additional amino acids from blood
  - Amino acids are deaminated:
    - Carbon chains broken down to provide ATP

Protein Metabolism

- Three Factors Against Protein Catabolism
  - Proteins are more difficult to break apart than complex carbohydrates or lipids
  - A by-product, ammonium ion, is toxic to cells
  - Proteins form the most important structural and functional components of cells

Amino Acids and Protein Synthesis

- Protein Synthesis
  - The body synthesizes half of the amino acids needed to build proteins
  - **Nonessential amino acids:**
    - Amino acids made by the body on demand

Amino Acids and Protein Synthesis

- Protein Synthesis
  - Ten **essential amino acids:**
    - Eight not synthesized:
      - isoleucine, leucine, lysine, threonine, tryptophan, phenylalanine, valine, and methionine
    - Two insufficiently synthesized:
      - arginine and histidine

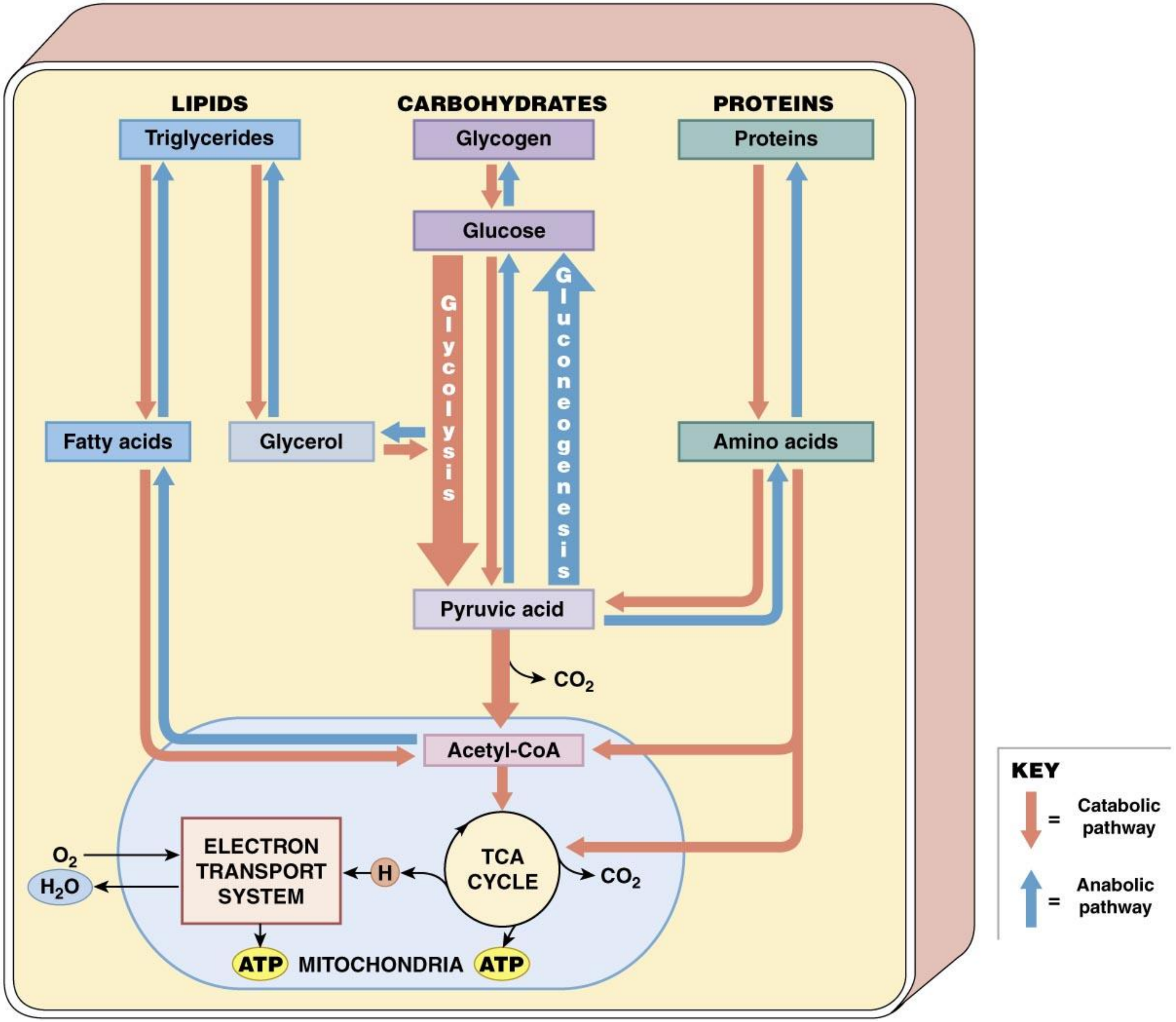

LIPIDS
CARBOHYDRATES
PROTEINS
Triglycerides
Glycogen
Proteins
Glucose
Glycolysis
Gluconeogenesis
Fatty acids
Glycerol
Amino acids
Pyruvic acid
CO_2
Acetyl-CoA
ELECTRON TRANSPORT SYSTEM
O_2
H_2O
H
TCA CYCLE
CO_2
ATP
MITOCHONDRIA
ATP
KEY
= Catabolic pathway
= Anabolic pathway

Figure 17-9

17-5 Nucleic acid catabolism involves RNA, but not DNA

RNA Catabolism

- Disassemble to nucleotides
- Sugar (ribose) and cytosine and uracil can be catabolized and enter TCA
- Adenine and guanine are not catabolized
  - Deaminized to uric acid for excretion:
    - gout

Nucleic Acid Synthesis

- DNA via replication
  - Prior to cell division
- RNA via transcription
  - Beginning of protein synthesis

17-6 Adequate nutrition is necessary to prevent deficiency disorders and maintain homeostasis

Nutrition

- Homeostasis can be maintained only if digestive tract absorbs enough fluids, organic substrates, minerals, and vitamins to meet cellular demands
- Nutrition is the absorption of nutrients from food
- The body's requirement for each nutrient varies

Nutrition

- Food Groups and MyPyramid Plan
  - A balanced diet contains all components needed to maintain homeostasis:
    - Substrates for energy generation
    - Essential amino acids and fatty acids
    - Minerals and vitamins
  - Must also include water to replace urine, feces, evaporation

TABLE 17-1 Basic Food Groups of the 2005 Dietary Guidelines and Their General Effects on Health

NUTRIENT GROUP	PROVIDES	HEALTH EFFECTS
Grains (recommended: at least half of the total eaten as 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)
Milk (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	Whole milk: High in calories, may cause weight gain; saturated fats correlated with heart disease
Meat and Beans (recommended: lean meats, fish, poultry, eggs, dry beans, nuts, legumes)	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

The MyPyramid Plan

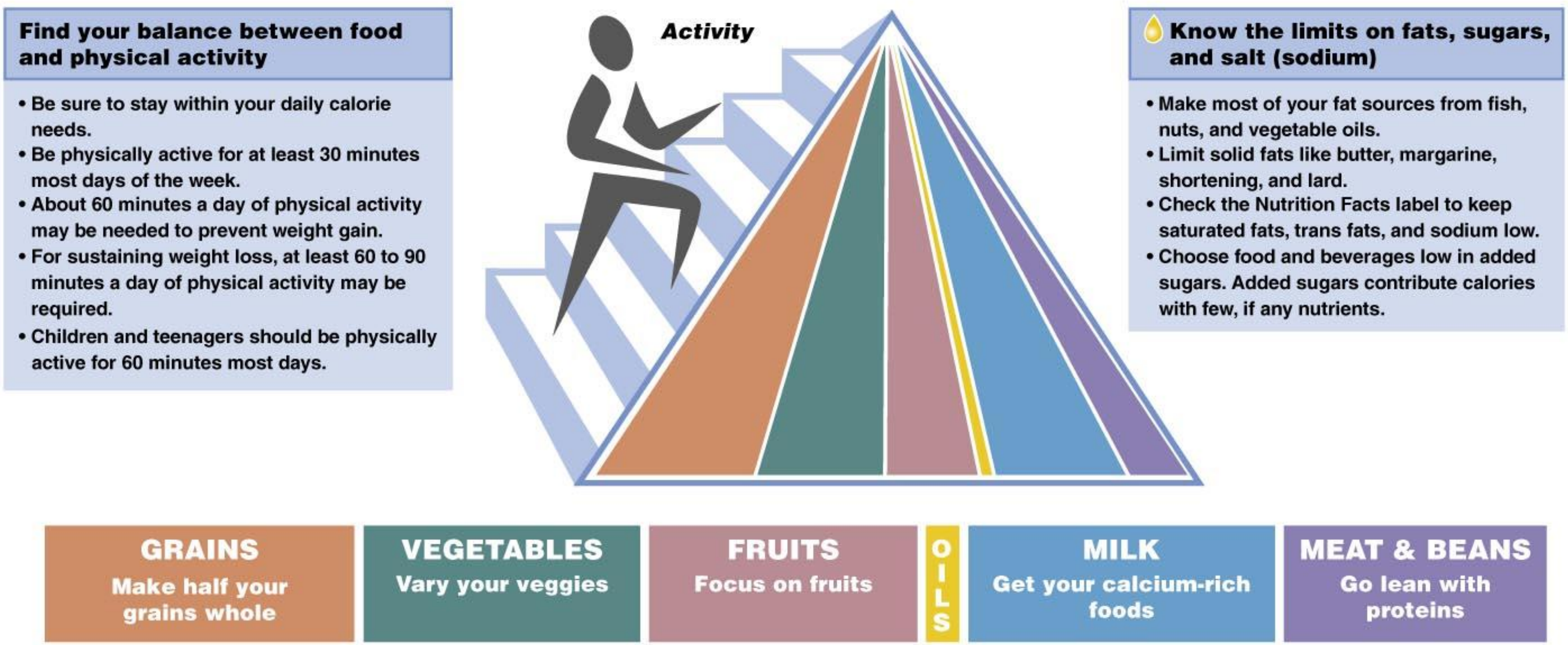


Figure 17-10

Minerals, Vitamins, and Water

- Are essential components of the diet
  - The body does not synthesize minerals
  - Cells synthesize only small quantities of a few vitamins:
    - Ions such as sodium and chloride determine the osmotic concentration of body fluids.
    - Ions in various combinations play major roles in important physiological processes.
    - Ions are essential cofactors in a variety of enzymatic reactions.

TABLE 17-2 Minerals and Mineral Reserves

MINERAL	SIGNIFICANCE	TOTAL BODY CONTENT	PRIMARY ROUTE OF EXCRETION	RECOMMENDED DAILY INTAKE
BULK MINERALS				
Sodium	Major cation in body fluids; essential for normal membrane function	110 g, primarily in body fluids	Urine, sweat, feces	1.5 g
Potassium	Major cation in cytoplasm; essential for normal membrane function	140 g, primarily in cytoplasm	Urine	4.7 g
Chloride	Major anion in body fluids	89 g, primarily in body fluids	Urine, sweat	2.3 g
Calcium	Essential for normal muscle and neuron function, and for normal bone structure	1.36 kg, primarily in skeleton	Urine, feces	1000–1200 mg
Phosphorus	As phosphate in high-energy compounds, nucleic acids, and bone matrix	744 g, primarily in skeleton	Urine, feces	700 mg
Magnesium	Cofactor of enzymes, required for normal membrane functions	29 g (skeleton, 17 g; cytoplasm and body fluids, 12 g)	Urine	310–400 mg

TABLE 17-2 Minerals and Mineral Reserves

MINERAL	SIGNIFICANCE	TOTAL BODY CONTENT	PRIMARY ROUTE OF EXCRETION	RECOMMENDED DAILY INTAKE
TRACE MINERALS				
Iron	Component of hemoglobin, myoglobin, cytochromes	3.9 g (1.6 g stored as ferritin or hemosiderin)	Urine (traces)	8–18 mg
Zinc	Cofactor of enzyme systems, notably carbonic anhydrase	2 g	Urine, hair (traces)	8–11 mg
Copper	Required as cofactor for hemoglobin synthesis	127 mg	Urine, feces (traces)	900 μg
Manganese	Cofactor for some enzymes	11 mg	Feces, urine (traces)	1.8–2.3 mg

Nutrition

- **Fat-Soluble Vitamins**
  - Vitamins A, D, E, and K:
    - Are absorbed primarily from the digestive tract along with lipids of micelles
    - Normally diffuse into plasma membranes and lipids in liver and adipose tissue

Nutrition

- Vitamin A
  - A structural component of visual pigment retinal
- Vitamin D
  - Is converted to calcitriol, which increases rate of intestinal calcium and phosphorus absorption
- Vitamin E
  - Stabilizes intracellular membranes
- Vitamin K
  - Helps synthesize several proteins, including three clotting factors

TABLE 17-3 The Fat-Soluble Vitamins

VITAMIN	SIGNIFICANCE	SOURCES	RECOMMENDED DAILY INTAKE	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	700–900 μg	Retarded growth, night blindness, deterioration of epithelial membranes	Liver damage, skin peeling, CNS effects (nausea, anorexia)
D (steroid-like compounds, including cholecalciferol or D_3)	Required for normal bone growth, calcium and phosphorus absorption at gut and retention at kidneys	Synthesized in skin exposed to sunlight	5–15 μg*	Rickets, skeletal deterioration	Calcium deposits in many tissues, disrupting functions
E (tocopherols)	Prevents breakdown of vitamin A and fatty acids	Meat, milk, vegetables	15 mg	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	90–120 μg	Bleeding disorders	Liver dysfunction, jaundice

*Recommended intakes are higher if sunlight exposure is inadequate for extended periods and alternative sources (fortified milk products) are unavailable.

Nutrition

- **Water-Soluble Vitamins**
  - Are components of coenzymes
  - Are rapidly exchanged between fluid in digestive tract and circulating blood:
    - Excesses are excreted in urine

TABLE 17-4 The Water-Soluble Vitamins

VITAMIN	SIGNIFICANCE	SOURCES	RECOMMENDED DAILY INTAKE	EFFECTS OF DEFICIENCY	EFFECTS OF EXCESS
B_1 (thiamine)	Coenzyme in decarboxylation reactions (removal of a carbon dioxide molecule)	Milk, meat, bread	1.1–1.2 mg	Muscle weakness, CNS and cardiovascular problems including heart disease; called *beriberi*	Hypotension
B_2 (riboflavin)	Part of FAD	Milk, meat	1.1–1.3 mg	Epithelial and mucosal deterioration	Itching, tingling
Niacin (nicotinic acid)	Part of NAD	Meat, bread, potatoes	14–16 mg	CNS, GI, epithelial, and mucosal deterioration; called *pellagra*	Itching, burning; vasodilation, death after large dose
B_5 (pantothenic acid)	Part of acetyl-CoA	Milk, meat	5 mg	Retarded growth, CNS disturbances	None reported
B_6 (pyridoxine)	Coenzyme in amino acid and lipid metabolism	Meat	1.3–1.7 mg	Retarded growth, anemia, convulsions, epithelial changes	CNS alterations, perhaps fatal

TABLE 17-4 The Water-Soluble Vitamins *(continued)*

VITAMIN	SIGNIFICANCE	SOURCES	RECOMMENDED DAILY INTAKE	EFFECTS OF DEFICIENCY	EFFECTS OF EXCESS
Folate (folic acid)	Coenzyme in amino acid and nucleic acid metabolisms	Vegetables, cereal, bread	400 µg	Retarded growth, anemia, gastrointestinal disorders, developmental abnormalities	Few noted except at massive doses
B_{12} (cobalamin)	Coenzyme in nucleic acid metabolism	Milk, meat	2.4 µg	Impaired RBC production causes *pernicious anemia*	Polycythemia (elevated hematocrit)
Biotin	Coenzyme in decarboxylation reactions	Eggs, meat, vegetables	30 µg	Fatigue, muscular pain, nausea, dermatitis	None reported
C (ascorbic acid)	Coenzyme; delivers hydrogen ions, antioxidant	Citrus fruits	75–90 mg Smokers: add 35mg	Epithelial and mucosal deterioration; called *scurvy*	Kidney stones

Nutrition

- Water
  - Need about 2500 mL/day
  - Requirements based on other metabolic factors

Diet and Disease

- Average U.S. diet contains excessive amounts of sodium, calories, and lipids
- Poor diet contributes to
  - Obesity
  - Heart disease
  - Atherosclerosis
  - Hypertension
  - Diabetes

17-7 Metabolic rate is the average caloric expenditure, and thermoregulation involves balancing heat-producing and heat-losing mechanisms

Metabolic Rate

- Energy Gains and Losses
  - Energy is released:
    - When chemical bonds are broken
  - In cells:
    - Energy is used to synthesize ATP
    - Some energy is lost as heat

Units of Energy

- **Calories**
  - Energy required to raise 1 g of water 1 degree Celsius is a **calorie (cal)**
  - Energy required to raise 1 kilogram of water 1 degree Celsius is a **Calorie (Cal)** = **kilocalorie (kcal)**
- The Energy Content of Food
  - Lipids release 9.46 Cal/g
  - Carbohydrates release 4.18 Cal/g
  - Proteins release 4.32 Cal/g

Energy Expenditure: Metabolic Rate

- Clinicians examine metabolism to determine calories used and measured in
  - Calories per hour
  - Calories per day
  - Calories per unit of body weight per day
- Metabolic rate is the sum of all anabolic and catabolic processes in the body
- Metabolic rate changes according to activity

Energy Expenditure: Metabolic Rate

- **Basal Metabolic Rate (BMR)**
  - Is the minimum resting energy expenditure:
    - Of an awake and alert person
    - Measured under standardized testing conditions
  - Measuring BMR:
    - Involves monitoring respiratory activity
    - Energy utilization is proportional to oxygen consumption

Energy Expenditure: Metabolic Rate

- Metabolic Rate
  - If daily energy intake exceeds energy demands:
    - Body stores excess energy as triglycerides in adipose tissue
  - If daily caloric expenditures exceed dietary supply:
    - Body uses energy reserves, loses weight

Thermoregulation

- Heat production
  - BMR estimates rate of energy use
  - Energy not captured is released as heat:
    - serves important homeostatic purpose

Thermoregulation

- Body Temperature
  - Enzymes operate in a limited temperature range
  - Homeostatic mechanisms keep body temperature within limited range (thermoregulation)

Thermoregulation

- Mechanisms of Heat Transfer
  – Heat exchange with environment involves four processes:
    - **Radiation**
    - **Conduction**
    - **Convection**
    - **Evaporation**

Thermoregulation

- Radiation
  - Warm objects lose heat energy as infrared radiation:
    - Depending on body and skin temperature
  - About 50% of indoor heat is lost by radiation
- Conduction
  - Is direct transfer of energy through physical contact
  - Is generally not effective in heat gain or loss

Thermoregulation

- Convection
  - Results from conductive heat loss to air at body surfaces
  - As body conducts heat to air, that air warms and rises and is replaced by cooler air
  - Accounts for about 15% of indoor heat loss
- Evaporation
  - Absorbs energy (0.58 Cal per gram of water evaporated)
  - Cools surface where evaporation occurs
  - Evaporation rates at skin are highly variable

Thermoregulation

- **Insensible Water Loss**
  - Each hour, 20–25 mL of water crosses epithelia and evaporates from alveolar surfaces and skin surface
  - Accounts for about 20% of indoor heat loss
- **Sensible Perspiration**
  - From sweat glands
  - Depends on wide range of activity:
    - From inactivity to secretory rates of 2–4 liters (2.1–4.2 quarts) per hour

Thermoregulation

- The Regulation of Heat Gain and Heat Loss
  - Is coordinated by **heat-gain center** and **heat-loss center** in preoptic area of anterior hypothalamus:
    - Modify activities of other hypothalamic nuclei

Thermoregulation

- Temperature Control
  - Is achieved by regulating:
    - Rate of heat production
    - Rate of heat loss to environment
  - Further supported by behavioral modifications

Thermoregulation

- Mechanisms for Increasing Heat Loss
  - When temperature at preoptic nucleus exceeds set point:
    - The heat-loss center is stimulated

Thermoregulation

- Three Actions of Heat-Loss Center
  - Inhibition of vasomotor center:
    - Causes peripheral vasodilation
    - Warm blood flows to surface of body and skin temperature rises
    - Radiational and convective losses increase
  - Sweat glands are stimulated to increase secretory output:
    - Perspiration flows across body surface
    - Evaporative heat losses increase
  - Respiratory centers are stimulated:
    - Depth of respiration increases

Thermoregulation

- Mechanisms for Promoting Heat Gain
  - The heat-gain center prevents low body temperature (**hypothermia**)
  - When temperature at preoptic nucleus drops:
    - Heat-loss center is inhibited
    - Heat-gain center is activated

Thermoregulation

- Heat Conservation
  - Sympathetic vasomotor center decreases blood flow to dermis:
    - Reducing losses by radiation, convection, and conduction
  - In cold conditions:
    - Blood flow to skin is restricted
    - Blood returning from limbs is shunted to deep, insulated veins (**countercurrent exchange**)

Thermoregulation

- Heat Dissipation
  - In warm conditions:
    - Blood flows to superficial venous network
    - Heat is conducted outward to cooler surfaces

Thermoregulation

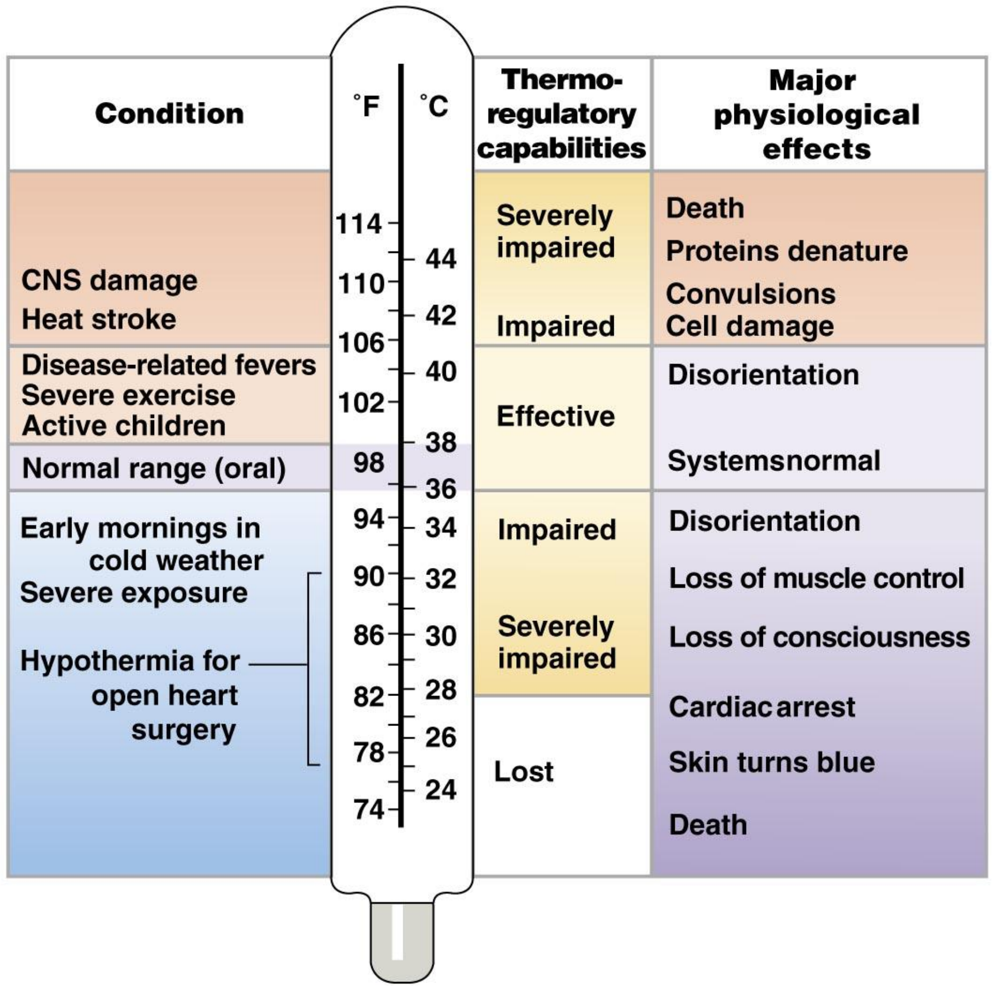


Figure 17-11

Thermoregulation

- Two mechanisms for generating heat
  - **Shivering thermogenesis:**
    - Increased muscle tone increases energy consumption of skeletal muscle, which produces heat
    - Involves agonists and antagonists, and degree of stimulation varies with demand
    - Shivering increases heat generation up to 400%
  - **Nonshivering thermogenesis:**
    - Releases hormones that increase metabolic activity
    - Raises heat production in adults 10% to 15% over extended time period

17-8 Caloric needs decline with advancing age

Nutrition and Aging

- For each decade after age 50, caloric requirements decrease by 10%.
  - Reductions in metabolic rates, body mass, activity levels, and exercise tolerance
- Increased need of calcium