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
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

- Catabolism
  - Organic molecules
    - Amino acids
    - Lipids
    - Simple sugars
  - Heat
- Nutrient Pool
- Anabolism
  - Results of Anabolism
    - Maintenance and repairs
    - Growth
    - Secretion
    - Stored reserves
- ATP
  - Other ATP Expenses
    - Locomotion
    - Contraction
    - Intracellular transport
    - Cytokinesis
    - Endocytosis
    - Exocytosis

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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:
  \[ \text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} \]
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)
Figure 17-3

**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.

**Energy Summary**

<table>
<thead>
<tr>
<th>Steps 1 &amp; 2:</th>
<th>-2 ATP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 5:</td>
<td>+4 ATP</td>
</tr>
<tr>
<td><strong>NET GAIN:</strong></td>
<td>+2 ATP</td>
</tr>
</tbody>
</table>

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• 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
  – H₂O molecules are tied up in two steps
  – CO₂ is a waste product
  – The product of one TCA cycle is:
    • One molecule of ATP
Energy Production Within Mitochondria

• Summary: The TCA Cycle

\[
\text{CH}_3\text{CO} - \text{CoA} + 3\text{NAD} + \text{FAD} + \text{GDP} + \text{P}_i + 2 \text{H}_2\text{O} \rightarrow \\
\text{CoA} + 2 \text{CO}_2 + 3\text{NADH} + \text{FADH}_2 + 2 \text{H}^+ + \text{ATP}
\]
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 $2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O}$
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)
Figure 17-5

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.

KEY
- Red: Flow of electrons
- Gray: Flow of $H^+$

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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)
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 B₆ (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
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>
<thead>
<tr>
<th>NUTRIENT GROUP</th>
<th>PROVIDES</th>
<th>HEALTH EFFECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grains (recommended: at least half of the total eaten as whole grains)</td>
<td>Carbohydrates; vitamins E, thiamine, niacin, folate; calcium; phosphorus; iron; sodium; dietary fiber</td>
<td>Whole grains prevent rapid rise in blood glucose levels, and consequent rapid rise in insulin levels</td>
</tr>
<tr>
<td>Vegetables (recommended: especially dark-green and orange vegetables)</td>
<td>Carbohydrates; vitamins A, C, E, folate; dietary fiber; potassium</td>
<td>Reduce risk of cardiovascular disease; protect against colon cancer (folate) and prostate cancer (lycopene in tomatoes)</td>
</tr>
<tr>
<td>Fruits (recommended: a variety of fruit each day)</td>
<td>Carbohydrates; vitamins A, C, E, folate; dietary fiber; potassium</td>
<td>Reduce risk of cardiovascular disease; protect against colon cancer (folate)</td>
</tr>
<tr>
<td>Milk (recommended: low-fat or fat-free milk, yogurt, and cheese)</td>
<td>Complete proteins; fats; carbohydrates; calcium; potassium; magnesium; sodium; phosphorus; vitamins A, B₁₂, pantothenic acid, thiamine, riboflavin</td>
<td>Whole milk: High in calories, may cause weight gain; saturated fats correlated with heart disease</td>
</tr>
<tr>
<td>Meat and Beans (recommended: lean meats, fish, poultry, eggs, dry beans, nuts, legumes)</td>
<td>Complete proteins; fats; calcium; potassium; phosphorus; iron; zinc; vitamins E, thiamine, B₆</td>
<td>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</td>
</tr>
</tbody>
</table>
The MyPyramid Plan

Find your balance between food and physical activity

- Be sure to stay within your daily calorie needs.
- 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.
- For sustaining 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.

Know the limits on fats, sugars, and salt (sodium)

- Make most of your fat sources from fish, nuts, and vegetable oils.
- Limit solid fats like butter, margarine, shortening, and lard.
- 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 calories with few, if any nutrients.

Figure 17-10

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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>
<thead>
<tr>
<th>MINERAL</th>
<th>SIGNIFICANCE</th>
<th>TOTAL BODY CONTENT</th>
<th>PRIMARY ROUTE OF EXCRETION</th>
<th>RECOMMENDED DAILY INTAKE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>Major cation in body fluids; essential for normal membrane function</td>
<td>110 g, primarily in body fluids</td>
<td>Urine, sweat, feces</td>
<td>1.5 g</td>
</tr>
<tr>
<td>Potassium</td>
<td>Major cation in cytoplasm; essential for normal membrane function</td>
<td>140 g, primarily in cytoplasm</td>
<td>Urine</td>
<td>4.7 g</td>
</tr>
<tr>
<td>Chloride</td>
<td>Major anion in body fluids</td>
<td>89 g, primarily in body fluids</td>
<td>Urine, sweat</td>
<td>2.3 g</td>
</tr>
<tr>
<td>Calcium</td>
<td>Essential for normal muscle and neuron function, and for normal bone structure</td>
<td>1.36 kg, primarily in skeleton</td>
<td>Urine, feces</td>
<td>1000–1200 mg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>As phosphate in high-energy compounds, nucleic acids, and bone matrix</td>
<td>744 g, primarily in skeleton</td>
<td>Urine, feces</td>
<td>700 mg</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Cofactor of enzymes, required for normal membrane functions</td>
<td>29 g (skeleton, 17 g; cytoplasm and body fluids, 12 g)</td>
<td>Urine</td>
<td>310–400 mg</td>
</tr>
<tr>
<td>MINERAL</td>
<td>SIGNIFICANCE</td>
<td>TOTAL BODY CONTENT</td>
<td>PRIMARY ROUTE OF EXCRETION</td>
<td>RECOMMENDED DAILY INTAKE</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------------------</td>
<td>---------------------------------------------------------</td>
<td>----------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td><strong>TRACE MINERALS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>Component of hemoglobin, myoglobin, cytochromes</td>
<td>3.9 g (1.6 g stored as ferritin or hemosiderin)</td>
<td>Urine (traces)</td>
<td>8–18 mg</td>
</tr>
<tr>
<td>Zinc</td>
<td>Cofactor of enzyme systems, notably carbonic anhydrase</td>
<td>2 g</td>
<td>Urine, hair (traces)</td>
<td>8–11 mg</td>
</tr>
<tr>
<td>Copper</td>
<td>Required as cofactor for hemoglobin synthesis</td>
<td>127 mg</td>
<td>Urine, feces (traces)</td>
<td>900 μg</td>
</tr>
<tr>
<td>Manganese</td>
<td>Cofactor for some enzymes</td>
<td>11 mg</td>
<td>Feces, urine (traces)</td>
<td>1.8–2.3 mg</td>
</tr>
</tbody>
</table>
• **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

<table>
<thead>
<tr>
<th>VITAMIN</th>
<th>SIGNIFICANCE</th>
<th>SOURCES</th>
<th>RECOMMENDED DAILY INTAKE</th>
<th>EFFECTS OF DEFICIENCY</th>
<th>EFFECTS OF EXCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Maintains epithelia; required for synthesis of visual pigments; supports immune system; promotes growth and bone remodeling</td>
<td>Leafy green and yellow vegetables</td>
<td>700–900 µg</td>
<td>Retarded growth, night blindness, deterioration of epithelial membranes</td>
<td>Liver damage, skin peeling, CNS effects (nausea, anorexia)</td>
</tr>
<tr>
<td>D (steroid-like compounds, including cholecalciferol or D₃)</td>
<td>Required for normal bone growth, calcium and phosphorus absorption at gut and retention at kidneys</td>
<td>Synthesized in skin exposed to sunlight</td>
<td>5–15 µg*</td>
<td>Rickets, skeletal deterioration</td>
<td>Calcium deposits in many tissues, disrupting functions</td>
</tr>
<tr>
<td>E (tocopherols)</td>
<td>Prevents breakdown of vitamin A and fatty acids</td>
<td>Meat, milk, vegetables</td>
<td>15 mg</td>
<td>Anemia, other problems suspected</td>
<td>Nausea, stomach cramps, blurred vision, fatigue</td>
</tr>
<tr>
<td>K</td>
<td>Essential for liver synthesis of prothrombin and other clotting factors</td>
<td>Vegetables; production by intestinal bacteria</td>
<td>90–120 µg</td>
<td>Bleeding disorders</td>
<td>Liver dysfunction, jaundice</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>VITAMIN</th>
<th>SIGNIFICANCE</th>
<th>SOURCES</th>
<th>RECOMMENDED DAILY INTAKE</th>
<th>EFFECTS OF DEFICIENCY</th>
<th>EFFECTS OF EXCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>B&lt;sub&gt;1&lt;/sub&gt; (thiamine)</td>
<td>Coenzyme in decarboxylation reactions (removal of a carbon dioxide molecule)</td>
<td>Milk, meat, bread</td>
<td>1.1–1.2 mg</td>
<td>Muscle weakness, CNS and cardiovascular problems including heart disease; called <em>beriberi</em></td>
<td>Hypotension</td>
</tr>
<tr>
<td>B&lt;sub&gt;2&lt;/sub&gt; (riboflavin)</td>
<td>Part of FAD</td>
<td>Milk, meat</td>
<td>1.1–1.3 mg</td>
<td>Epithelial and mucosal deterioration</td>
<td>Itching, tingling</td>
</tr>
<tr>
<td>Niacin (nicotinic acid)</td>
<td>Part of NAD</td>
<td>Meat, bread, potatoes</td>
<td>14–16 mg</td>
<td>CNS, GI, epithelial, and mucosal deterioration; called <em>pellagra</em></td>
<td>Itching, burning; vasodilation, death after large dose</td>
</tr>
<tr>
<td>B&lt;sub&gt;3&lt;/sub&gt; (pantothenic acid)</td>
<td>Part of acetyl-CoA</td>
<td>Milk, meat</td>
<td>5 mg</td>
<td>Retarded growth, CNS disturbances</td>
<td>None reported</td>
</tr>
<tr>
<td>B&lt;sub&gt;6&lt;/sub&gt; (pyridoxine)</td>
<td>Coenzyme in amino acid and lipid metabolism</td>
<td>Meat</td>
<td>1.3–1.7 mg</td>
<td>Retarded growth, anemia, convulsions, epithelial changes</td>
<td>CNS alterations, perhaps fatal</td>
</tr>
<tr>
<td>VITAMIN</td>
<td>SIGNIFICANCE</td>
<td>SOURCES</td>
<td>RECOMMENDED DAILY INTAKE</td>
<td>EFFECTS OF DEFICIENCY</td>
<td>EFFECTS OF EXCESS</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------------------------------------------</td>
<td>---------------</td>
<td>--------------------------</td>
<td>----------------------------------------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Folate (folic acid)</td>
<td>Coenzyme in amino acid and nucleic acid metabolisms</td>
<td>Vegetables, cereal, bread</td>
<td>400 µg</td>
<td>Retarded growth, anemia, gastrointestinal disorders, developmental abnormalities</td>
<td>Few noted except at massive doses</td>
</tr>
<tr>
<td>$B_{12}$ (cobalamin)</td>
<td>Coenzyme in nucleic acid metabolism</td>
<td>Milk, meat</td>
<td>2.4 µg</td>
<td>Impaired RBC production causes <em>pernicious anemia</em></td>
<td>Polycythemia (elevated hematocrit)</td>
</tr>
<tr>
<td>Biotin</td>
<td>Coenzyme in decarboxylation reactions</td>
<td>Eggs, meat, vegetables</td>
<td>30 µg</td>
<td>Fatigue, muscular pain, nausea, dermatitis</td>
<td>None reported</td>
</tr>
<tr>
<td>C (ascorbic acid)</td>
<td>Coenzyme; delivers hydrogen ions, antioxidant</td>
<td>Citrus fruits</td>
<td>75–90 mg Smokers: add 35mg</td>
<td>Epithelial and mucosal deterioration; called <em>scurvy</em></td>
<td>Kidney stones</td>
</tr>
</tbody>
</table>
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.
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

![Thermoregulation Chart](image)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Thermoregulatory capabilities</th>
<th>Major physiological effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNS damage Heat stroke</td>
<td>Severely impaired</td>
<td>Death</td>
</tr>
<tr>
<td>Disease-related fevers Severe exercise Active children</td>
<td>Impaired</td>
<td>Proteins denature Convulsions Cell damage</td>
</tr>
<tr>
<td>Normal range (oral)</td>
<td>Effective</td>
<td>Disorientation</td>
</tr>
<tr>
<td>Early mornings in cold weather Severe exposure</td>
<td>Impaired</td>
<td>Systems normal</td>
</tr>
<tr>
<td>Hypothermia for open heart surgery</td>
<td>Severely impaired</td>
<td>Disorientation</td>
</tr>
<tr>
<td></td>
<td>Lost</td>
<td>Loss of muscle control Loss of consciousness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cardiac arrest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skin turns blue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Death</td>
</tr>
</tbody>
</table>

**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
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