CHAPTER 17

Metabolism and Energetics
Chapter 17 Learning Outcomes

17-1
- Define metabolism and energetics, and explain why cells need to synthesize new organic molecules.

17-2
- Describe the basic steps involved in glycolysis, the citric acid cycle, and the electron transport system, and summarize the energy yields of glycolysis and cellular respiration.

17-3
- Describe the pathways involved in lipid metabolism, and summarize mechanisms of lipid transport and distribution.

17-4
- Discuss protein metabolism and the use of proteins as an energy source.
Chapter 17 Learning Outcomes

- 17-5
  - Discuss nucleic acid metabolism and the limited use of nucleic acids as an energy source.

- 17-6
  - Explain what constitutes a balanced diet, and why such a diet is important.

- 17-7
  - Define metabolic rate, describe the factors involved in determining an individual's BMR, and discuss the homeostatic mechanisms that maintain a constant body temperature.

- 17-8
  - Describe the age-related changes in dietary requirements.
Nutrients and Energetics (17-1)

• **Nutrients**
  
  • Essential substances needed for cells to generate energy in the form of ATP
  
  • ATP supports cell growth and division, contraction, secretion, and other functions

• **Energetics**

  • The study of flow of energy and how it changes from one form to another
Metabolism (17-1)

- The sum total of all chemical reactions in the body
  - Cellular metabolism provides energy needed for homeostasis

- **Catabolism**
  - Breakdown of organic molecules for synthesis of ATP

- **Anabolism**
  - Synthesis of new organic molecules for storage
Figure 17-1 Cellular Metabolism.

- **INTERSTITIAL FLUID**
- **Plasma membrane**

**Organic Molecules**
- Amino acids
- Lipids
- Simple sugars

**Results of Anabolism**
- Maintenance and repairs
- Growth
- Secretion
- Stored nutrient reserves

**Aerobic Metabolism**
(in mitochondria)
- 40%
- ATP

**Anaerobic catabolism** in the cytosol releases small amounts of ATP that are significant only under unusual conditions.

**Other ATP Expenses**
- Locomotion
- Contraction
- Intracellular transport
- Cytokinesis
- Endocytosis
- Exocytosis

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Four Reasons to Synthesize New Compounds (17-1)

1. To perform structural maintenance and repairs
   - Metabolic turnover is ongoing removal and replacement of cell structures

2. To support growth

3. To produce secretions

4. To build nutrient reserves
   - Glucose stored as glycogen, triglycerides in adipose tissue
Nutrient Pool (17-1)

- Source for both catabolism and anabolism
  - Anabolic activities require amino acids, some lipids, and few carbohydrates
  - Catabolic reactions break down carbohydrates first, then lipids, and rarely amino acids
  - Mitochondria use specific organic molecules to form ATP, water, and carbon dioxide
    - Utilizes the citric acid cycle and the electron transport chain
Figure 17-2 Nutrient Use in Cellular Metabolism.

Structural, functional, and storage components
- Triglycerides
- Glycogen
- Proteins

Nutrient pool
- Fatty acids
- Glucose
- Amino acids

Small carbon chains

MITOCHONDRIA
- Citric acid cycle
- Coenzymes
- Electron transport system

ATP

O₂

H₂O

CO₂
Checkpoint (17-1)

1. Define energetics.

2. Define metabolism.

3. Compare catabolism and anabolism.
• Most cells use glucose to form ATP
  
  \[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \] and 36 ATP

  • Glucose + oxygen yields carbon dioxide + water and 36 molecules of ATP

• Anaerobic metabolism

  • Does not require oxygen

• Aerobic metabolism or cellular respiration

  • Requires oxygen, occurs in mitochondria
Glycolysis (17-2)

- Breakdown of glucose to two pyruvic acid molecules
  - $C_6H_{12}O_6 \rightarrow 2CH_3—CO—COOH^-$
  - Loses an $H^+$, becomes **pyruvate**, enters mitochondria

- Glycolysis requires:
  - Glucose and cytoplasmic enzymes
  - ATP and ADP, **NAD** – a coenzyme that removes $H^+$
  - Invest 2 ATP, produce 4 ATP, for a net gain of 2 ATP
Figure 17-3 Glycolysis.

Steps in Glycolysis

1. As soon as a glucose molecule enters the cytosol, 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
Steps 1 & 2: \(-2\) ATP
Step 5: \(+4\) ATP
NET GAIN: \(+2\) ATP
Mitochondrial Structure (17-2)

- Surrounded by two membranes
  - Outer is permeable to pyruvate
  - Inner uses carrier protein to transport pyruvate into mitochondrial matrix
- Citric acid cycle occurs within mitochondria
The Citric Acid Cycle (17-2)

- Also called tricarboxylic acid (TCA) or Krebs cycle
- Pyruvate interacts with NAD and coenzyme A (CoA)
  - Product is acetyl-CoA
  - Goes through citric acid cycle, transferring H⁺ to NAD and FAD
  - Forms ATP from GTP, NADH, and FADH₂
  - NADH and FADH₂ transfer H⁺ to electron transport system
An overview of the citric acid cycle, showing the distribution of carbon, hydrogen, and oxygen atoms.
The Electron Transport System (17-2)

- **ETS**
- Embedded in inner mitochondrial membrane
- Provides 95 percent of all cellular energy
- A series of protein-pigment *cytochromes*
- Electrons from $H^+$ enter ETS
  - Travel along the ETS and release energy
  - Energy drives $H^+$ pumps creating gradient for $H^+$
  - Gradient energy converts ADP to ATP
Figure 17-5 The Electron Transport System (ETS) and ATP Formation.

Hydrogen atoms from NADH and FADH$_2$ are split into electrons and protons. The protons (H$^+$) are released and coenzyme Q passes the electrons to the electron transport system.
Summary of Energy Yield from Carbohydrates (17-2)

- Glycolysis in cytoplasm yields 2 ATP and 2 pyruvate
- Citric acid cycle yields 2 ATP, one from each pyruvate
- ETS yields 28 ATP
- Sum total from one molecule of glucose is 36 ATP
  - All but two are produced in mitochondria
Figure 17-6 A Summary of the Energy Yield of Aerobic Metabolism.

Glycolysis (Anaerobic):
- 2 ATP
- 2 NAD
- 2 NADH
- 2 Acetyl CoA
- 2 ATP

Citric Acid Cycle (2 turns):
- 6 NADH
- 2 FADH₂
- 2 ATP

The Electron Transport System and Citric Acid Cycle (Aerobic):
- 2 ATP
- 24 ATP
- 4 ATP
- 4 ATP
- 34 ATP
- 36 ATP net gain to cell from complete catabolism of one glucose molecule

Energy Summary
Gluconeogenesis (17-2)

- The synthesis of "new" glucose from non-carbohydrate molecules
  - Needed because glycolysis is not a reversible reaction
    - Pyruvate cannot be converted back to glucose
  - Instead, cells use other 3-carbon molecules
    - Lactate, glycerol, some amino acids
  - Glucose from gluconeogenesis can undergo further catabolic reactions to be stored as glycogen
The reaction that converts pyruvate to acetyl-CoA cannot be reversed.

Some amino acids

Figure 17-7 Carbohydrate Metabolism.
Alternate Catabolic Pathways (17-2)

• Aerobic glucose metabolism is most efficient
• Without oxygen, cells will die
• Without glucose, cells find alternatives
  • First, will switch to lipid-based ATP production
  • Proteins catabolized only under starvation conditions
  • Nucleic acids rarely catabolized for energy
Triglycerides → Fatty acids → Pyruvate → Acetyl CoA → Citric acid cycle

Glycerol → Pyruvate → Acetyl CoA → Citric acid cycle

Glycogen → Glucose → Pyruvate → Acetyl CoA → Citric acid cycle

Proteins → Amino acids → Pyruvate → Acetyl CoA → Citric acid cycle
4. What is the primary role of the citric acid cycle in the production of ATP?

5. Hydrogen cyanide gas is a poison that produces its lethal effect by binding to the last cytochrome molecule in the electron transport system. What effect would this have at the cellular level?

6. Define gluconeogenesis.
Lipid Catabolism (17-3)

- Also called **lipolysis**
  - Hydrolysis reaction breaks triglycerides into glycerol and three fatty acids
    - One 18-carbon fatty acid can yield 144 ATP
  - Glycerol is converted to pyruvate, enters citric acid cycle
- Fatty acids undergo **beta-oxidation**
  - Occurs in mitochondria, generates NADH and FADH$_2$
  - Some fragments combine to form *ketone bodies*
Lipids and Energy Production (17-3)

- Lipids are stored in fat droplets
  - Difficult for water-soluble enzymes to reach lipid
    - Lipids can provide a lot of energy, but not quickly
  - Skeletal muscle fibers access glucose for quick energy
  - Skeletal muscle fibers access fatty acids during rest
Lipid Synthesis (17-3)

- Also called **lipogenesis**
- Glycerol is synthesized from a product of glycolysis
- Other lipids, steroids, and fatty acids are derived from acetyl-CoA
- Body cannot build every fatty acid it needs
  - **Essential fatty acids** must be in diet
Lipid Transport and Distribution (17-3)

- Lipids not soluble in water, need transport mechanisms
- Most circulated in plasma as lipoproteins
- Free fatty acids (FFA)
  - Come from catabolized adipose tissue, available during starvation periods
  - Bind to albumin for transport
Lipoproteins (17-3)

- Contain triglycerides and cholesterol, covered in phospholipids and proteins

- *Chylomicrons* in intestinal epithelium are largest

- **Low-density lipoproteins (LDLs)**
  - "Bad cholesterol" deposited in arterial plaques

- **High-density lipoproteins (HDLs)**
  - "Good cholesterol" transports cholesterol to liver
The liver absorbs chylomicrons from the bloodstream and removes the triglycerides. It combines the cholesterol from the chylomicron with synthesized or recycled cholesterol, and alters the surface proteins. It then releases low-density lipoproteins (LDLs) into the circulation, which deliver cholesterol to peripheral tissues. Some of the cholesterol is used by the liver to synthesize bile salts; excess cholesterol is excreted in the bile.

The HDLs return the cholesterol to the liver where it is extracted, and packaged in new LDLs or excreted with bile salts in bile.

The cell extracts the cholesterol and uses it in various ways. Excess cholesterol is excreted with the bile salts.

Once in peripheral tissues, the LDLs are absorbed.

The LDLs released by the liver leave the bloodstream and enter capillaries.

The cholesterol not used by the cells re-enters the bloodstream. There it gets absorbed by high density lipoproteins (HDLs).

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7. Define lipolysis.


9. Why are high-density lipoproteins (HDLs) considered beneficial?
Protein Metabolism (17-4)

- Usually proteins are recycled inside cells
  - Proteins are broken down, amino acids are used to synthesize new proteins
- If carbohydrates and lipids are not available for energy:
  - Amino acids can undergo catabolism in the citric acid cycle
  - ATP benefits vary, but average that of carbohydrates
Amino Acid Catabolism (17-4)

- Removal of amino group requires vitamin B$_6$
- **Transamination** moves amino group to other small carbon chain
  - Forms "new" amino acid
- **Deamination** prepares amino acid for the citric acid cycle
  - Removes amino group and forms ammonium ion (NH$_4^+$)
  - Liver cells combine CO$_2$ with NH$_4^+$ to produce urea
  - Eliminated in urine
Amino Acid Catabolism (17-4)

• Carbon chains, depending on structure, can:
  • Be converted to pyruvate and go through gluconeogenesis
  • Or be converted to acetyl-CoA and go through the citric acid cycle
  • Or be converted to ketone bodies
    • Acetone is one example, gives breath distinctive odor
    • Ketone bodies can be used by other cells that convert them back into acetyl-CoA
    • High ketone body concentration is called ketosis
Amino Acid Catabolism (17-4)

- An impractical source of quick energy because:
  1. Proteins are more difficult to break apart than fats and carbohydrates
  2. Ammonium ions are toxic to cells
  3. Structural proteins are essential for homeostasis

- Catabolism can alter cellular and systemic functions
Amino Acid and Protein Synthesis (17-4)

• **Nonessential amino acids**
  
  • Can be synthesized in cells through **amination** or transamination

• **Essential amino acids**
  
  • Must be included in diet
  
  • Include *isoleucine, leucine, lysine, threonine, tryptophan, phenylalanine, valine, methionine, arginine, and histidine*
Protein Deficiency Diseases (17-4)

• Inadequate consumption of essential amino acids

• Caused by malnutrition

• Inherited metabolic disorders

  • For example, **phenylketonuria (PKU)**
    • Cannot convert phenylalanine to tyrosine due to defective enzyme
    • Reaction essential to produce norepinephrine, epinephrine, and melanin
    • Infants' CNS development is inhibited
10. Define transamination.

11. Define deamination.

12. How would a diet deficient in vitamin B₆ affect protein metabolism?
Figure 17-10 A Summary of Catabolic and Anabolic Pathways.
RNA Catabolism (17-5)

- Broken into individual nucleotides
  - Most are recycled
  - Some broken down, but only sugar, cytosine, uracil can go through the citric acid cycle to generate ATP
  - Adenine and guanine are deaminated, excreted as uric acid
    - Hyperuricemia can cause crystals to form
    - Causes gout
Nucleic Acid Synthesis (17-5)

- DNA synthesis occurs only in mitosis and meiosis
- Most cells synthesize RNA
  - Transcribed by RNA polymerase
  - Messenger RNA only when needed and is short-lived
  - Ribosomal RNA and transfer RNA are longer lasting
13. Why do cells not use DNA as an energy source?

14. What are nitrogenous wastes?

15. Elevated levels of uric acid in the blood could indicate an increased catabolic rate for which type of macromolecule?
Adequate Nutrition (17-6)

- **Nutrition**
  - The absorption of essential nutrients

- **Balanced diet**
  - Contains all nutrients needed for homeostasis
  - Prevents **malnutrition**
Food Groups and MyPlate (17-6)

- USDA food guide www.choosemyplate.gov

- Five basic food groups
  1. Grains
  2. Vegetables
  3. Fruits
  4. Dairy
  5. Protein
Balanced Diets (17-6)

• Meet quantity and quality requirements

• **Complete proteins**
  • Found in meat, eggs, dairy
  • Have all essential amino acids and vitamin $B_{12}$

• **Incomplete proteins**
  • Found in grains, fruits, and vegetables
  • Vegetarians require balance and fortified cereal or tofu
Figure 17-11 The MyPlate Food Guide.
### Table 17-1 Basic Food Groups and Their Effects on Health

<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 should be 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>Dairy (recommended: low-fat or fat-free milk, yogurt, and cheese)</td>
<td>Complete proteins; fats; carbohydrates; calcium; potassium; magnesium; sodium; phosphorus; vitamins A, B&lt;sub&gt;12&lt;/sub&gt;, pantothenic acid, thiamine, riboflavin</td>
<td>Good source of calcium, which strengthens bones; Whole milk: High in calories, may cause weight gain; saturated fats correlated with heart disease</td>
</tr>
<tr>
<td>Protein (recommended: lean meats, fish, poultry, eggs, dry beans, nuts, legumes)</td>
<td>Complete proteins; fats; calcium; potassium; phosphorus; iron; zinc; vitamins E, thiamine, B&lt;sub&gt;6&lt;/sub&gt;</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>
Minerals (17-6)

- Inorganic ions from dissociation of electrolytes
- Required in diet because:
  1. \( \text{Na}^+ \) and \( \text{Cl}^- \) determine osmotic concentration of body fluids
  2. Various ions needed in maintaining membrane potential, muscle contraction, buffers, etc.
  3. Ions function as cofactors in enzymatic reactions
### Table 17-2 Minerals and Mineral Reserves

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Significance</th>
<th>Total Body Content</th>
<th>Primary Route of Excretion</th>
<th>Recommended Daily Allowance (RDA) in mg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BULK MINERALS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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>1500</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>4700</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>2300</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</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</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</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</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</td>
</tr>
<tr>
<td>Copper</td>
<td>Required as cofactor for hemoglobin synthesis</td>
<td>127 mg</td>
<td>Urine, feces (traces)</td>
<td>0.9</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</td>
</tr>
</tbody>
</table>
Fat-Soluble Vitamins (17-6)

- Vitamins A, D, E, and K
- Absorbed from the digestive tract
- Can be stored easily in cells
- **Avitaminosis** (or *vitamin deficiency disease*)
  - Rarely occurs due to lack of fat-soluble vitamins
- Hypervitaminosis
  - Excess fat-soluble vitamins build up in storage
Water-Soluble Vitamins (17-6)

- Most are components of coenzymes
- Easily absorbed from the gut
- Excess readily excreted in urine
- Gut bacteria help prevent avitaminosis
- Hypervitaminosis
  - Occurs rarely and usually when taking excessive vitamin supplements
<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Significance</th>
<th>Sources</th>
<th>Recommended Daily Allowance (RDA) in mg</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>0.7–0.9</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, intestinal calcium and phosphorus absorption and their retention at kidneys</td>
<td>Synthesized in skin exposed to sunlight</td>
<td>0.005–0.015*</td>
<td>Rickets, skeletal deterioration</td>
<td>Calcium deposits in many tissues, disrupting functions</td>
</tr>
<tr>
<td>E</td>
<td>Prevents breakdown of vitamin A and fatty acids</td>
<td>Meat, milk, vegetables</td>
<td>15</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>0.09–0.12</td>
<td>Bleeding disorders</td>
<td>Liver dysfunction, jaundice</td>
</tr>
</tbody>
</table>

*Unless exposure to sunlight is inadequate for extended periods and alternative sources (fortified milk products) are unavailable.
### Table 17-4 The Water-Soluble Vitamins

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Significance</th>
<th>Sources</th>
<th>Recommended Daily Allowance (RDA) in mg</th>
<th>Effects of Deficiency</th>
<th>Effects of Excess</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_1$ (thiamine)</td>
<td>Coenzyme in many pathways</td>
<td>Milk, meat, bread</td>
<td>1.1–1.2</td>
<td>Muscle weakness, CNS and cardiovascular problems including heart disease; called <em>beriberi</em></td>
<td>Hypotension</td>
</tr>
<tr>
<td>$B_2$ (riboflavin)</td>
<td>Part of FAD</td>
<td>Milk, meat, eggs, cheese</td>
<td>1.1–1.3</td>
<td>Epithelial and mucosal deterioration</td>
<td>Itching, tingling</td>
</tr>
<tr>
<td>$B_3$ (niacin, nicotinic acid)</td>
<td>Part of NAD</td>
<td>Meat, bread, potatoes</td>
<td>14–16</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>$B_5$ (pantothenic acid)</td>
<td>Part of coenzyme A</td>
<td>Milk, meat</td>
<td>10</td>
<td>Retarded growth, CNS disturbances</td>
<td>None reported</td>
</tr>
<tr>
<td>$B_6$ (pyridoxine)</td>
<td>Coenzyme in amino acid and lipid metabolism</td>
<td>Meat, whole grains, vegetables, orange juice, cheese, milk</td>
<td>1.3–1.7</td>
<td>Retarded growth, anemia, convulsions, epithelial changes</td>
<td>CNS alterations, perhaps fatal</td>
</tr>
<tr>
<td>$B_7$ (biotin)</td>
<td>Coenzyme in many pathways</td>
<td>Eggs, meat, vegetables</td>
<td>0.03</td>
<td>Fatigue, muscular pain, nausea, dermatitis</td>
<td>None reported</td>
</tr>
<tr>
<td>$B_9$ (folic acid, folate)</td>
<td>Coenzyme in amino acid and nucleic acid metabolisms</td>
<td>Leafy vegetables, some fruits, liver, cereal, bread</td>
<td>0.2–0.4</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>0.0024</td>
<td>Impaired RBC production, causing <em>pernicious anemia</em></td>
<td>Polycythemia (elevated hematocrit)</td>
</tr>
<tr>
<td>C (ascorbic acid)</td>
<td>Coenzyme in many pathways</td>
<td>Citrus fruits</td>
<td>75–90; Smokers add 35 mg</td>
<td>Epithelial and mucosal deterioration; called <em>scurvy</em></td>
<td>Kidney stones</td>
</tr>
</tbody>
</table>
Water (17-6)

• Basic daily requirement is 2.5 L/day
  • May need more or less based on activity and body temp
  • Most obtained through consumed food and water
  • Some a product of ETS in mitochondria
Diet and Disease (17-6)

• Long-term issues result from unbalanced diet

• U.S. diets too high in sodium, lipids, and calories

  • Results are epidemic-proportioned incidence of:

    • Obesity

    • Heart and vascular diseases

    • Hypertension

    • Diabetes
16. Identify the two types of vitamins.

17. What is the difference between foods described as containing complete proteins and those described as containing incomplete proteins?

18. How would a decrease in the amount of bile salts in the bile affect the amount of vitamin A in the body?
Units of Energy (17-7)

- **Calorie** – unit of heat energy
  - Metabolic reactions release heat
  - **Calorie (cal)** is the amount of energy required to raise temp of 1 gram of water 1 degree Celsius
- **Kilocalorie (kcal) or Calorie (Cal)**
  - More practical in human metabolic studies
  - Amount of energy required to raise 1 kg of water 1°C
The Energy Content of Food (17-7)

• **Calorimeter**
  - A test chamber where food, water, and oxygen are ignited
  - Food is completely burned to ash
  - Water temp before and after test is compared

• **Catabolism of:**
  - Lipids release 9.46 Cal/g
  - Proteins and carbohydrates 4.32 and 4.18 Cal/g, respectively
Energy Expenditure: Metabolic Rate (17-7)

• Measure of sum of all anabolic and catabolic reactions in body
  • Units of Cal/hour, Cal/day, or Cal/unit body weight/day

• Basal metabolic rate (BMR)
  • Testing done under resting, fasting conditions
  • Average BMR is 70 Cal/hour
  • Variations due to age, sex, condition, weight, and genetics
Figure 17-12 Caloric Expenditures for Various Activities.

Estimated calories expended by a 70 kg (154 lb) individual.
Balance of Caloric Intake and Output (17-7)

- Weight gain occurs if energy intake exceeds output
- Weight loss occurs if energy intake is lower than output
- Best weight-control programs have both:
  - Calorie counting
  - Increase in daily exercise
Thermoregulation (17-7)

- Homeostatic process of maintaining body temperature
  - In spite of external environment
  - Required to maintain enzymatic viability
  - Body temp below 36°C or above 40°C causes disorientation
  - Above 42°C causes convulsions and permanent cell damage
Mechanisms of Heat Transfer (17-7)

1. **Radiation**
   - Accounts for more than half of body's heat loss
   - Heat is lost as infrared radiation

2. **Conduction**
   - Direct transfer due to physical contact with cold object
   - Not very effective in gaining or losing heat
3. **Convection**
   - Conductive heat loss to the air
   - Heat rises away from skin, cool air replaces it

4. **Evaporation**
   - Water changes from liquid to vapor, absorbing energy
     - *Sensible perspiration* from sweat glands varies
     - *Insensible perspiration* from lungs and skin is consistent
Figure 17-13 Mechanisms of Heat Transfer.

- Radiation
- Evaporation
- Convection
- Conduction
Mechanisms of Temperature Balance (17-7)

- Altering heat gain and heat loss activities
  - Coordinated by **heat-loss center** and **heat-gain center**
    - In hypothalamus
    - Heat-loss uses parasympathetic pathways
    - Heat-gain uses sympathetic pathways
When body temp rises above set point:

1. Vasomotor center inhibited
   - Peripheral blood vessels dilate
     - Increased radiation and convection

2. Sweat glands stimulated
   - Increased evaporation

3. Respiratory center stimulated
   - Increased evaporation from lungs
Promoting Heat Gain (17-7)

- To prevent **hypothermia**, heat-loss center is inhibited, heat-gain center is activated
  - Stimulates vasomotor center
    - Vasoconstriction limits radiation, convection, conduction
  - *Shivering thermogenesis*
    - Activates brief contractions of skeletal muscles
  - *Nonshivering thermogenesis* is stimulated hormonally
    - Thyroid hormones and epinephrine
19. Compare a pregnant woman's BMR (basal metabolic rate) to her BMR when she is not pregnant.

20. Under what conditions would evaporative cooling of the body be ineffective?

21. What effect would vasoconstriction of peripheral blood vessels have on body temperature on a hot day?
Caloric Needs Decline with Age (17-8)

• Nutritionally required quality and balance of food doesn't change with age

• Caloric requirement does decrease about 10 percent after age 50

• Need for calcium and vitamin D₃ increases
  • Need to support skeletal system

• Elderly on low income may lack protein and iron
22. Which changes with aging: nutritional requirements or caloric requirements?