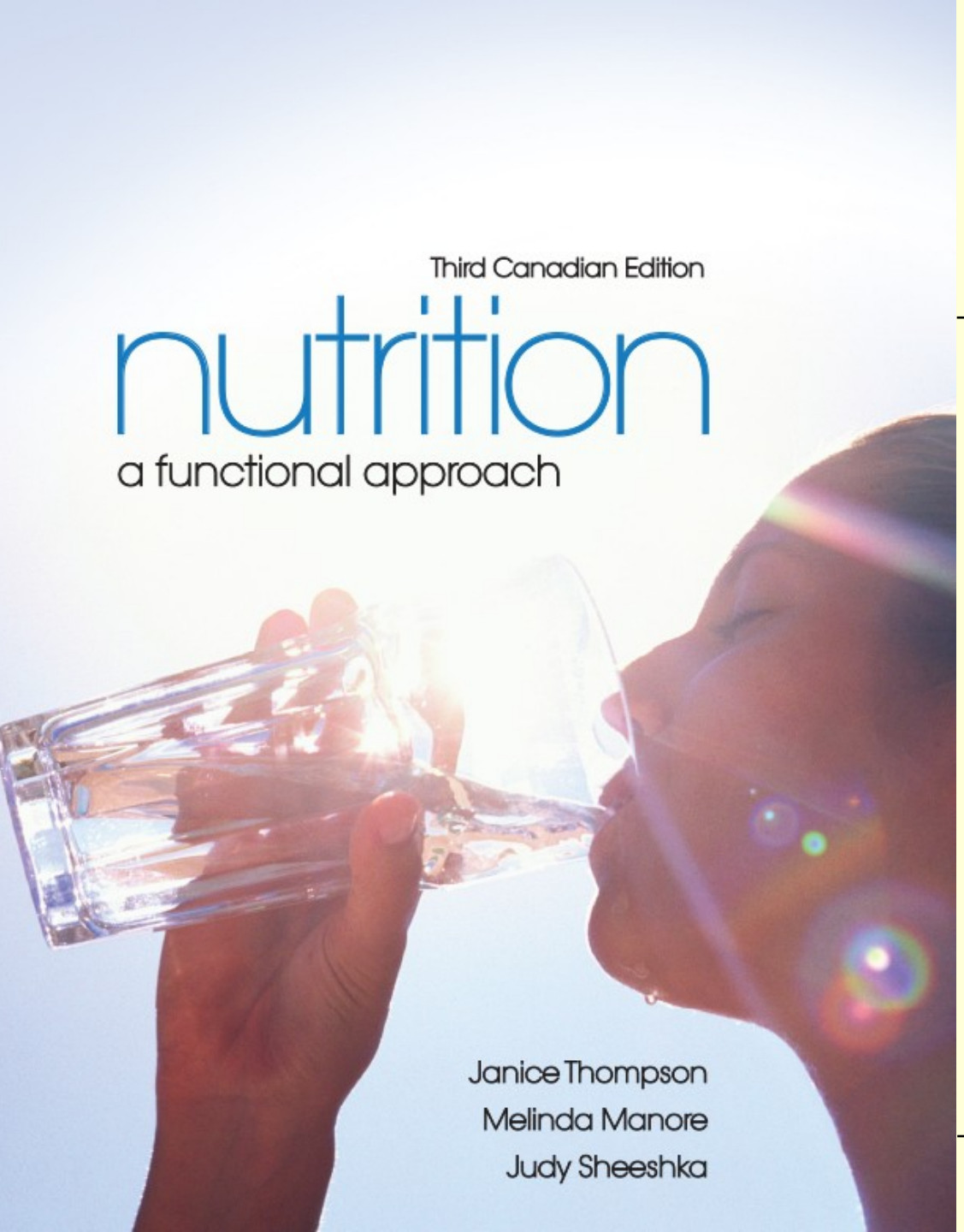


CHAPTER

6

Proteins: Crucial Components of All Body Tissues and In Depth

What Are Proteins?

Proteins: large complex molecules composed of amino acids

Contain carbon, hydrogen, oxygen, and nitrogen

Primary source of nitrogen in the diet

20 different amino acids are used to make proteins

Structure of an Amino Acid

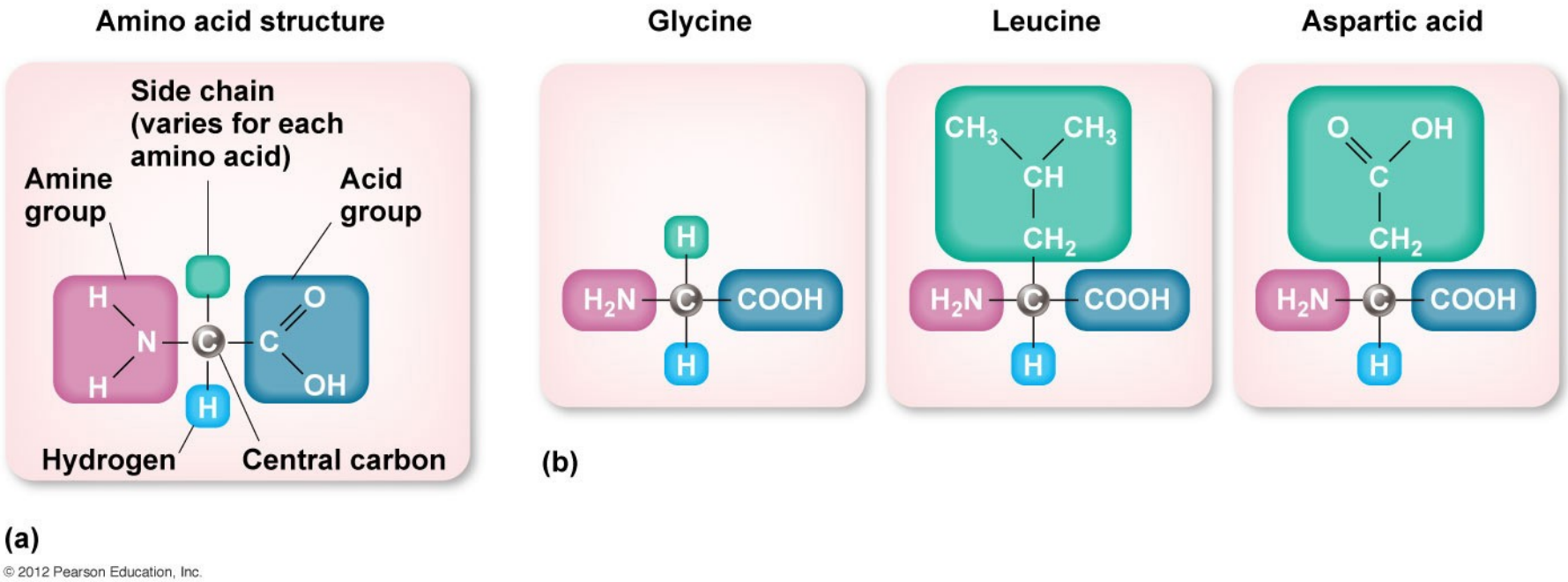


Figure 6.1

Amino Acids

Essential amino acids

- Cannot be produced by our bodies
- Must be obtained from food
- 9 of 20 are essential

Nonessential amino acids

- Can be made by our bodies
- Made by transferring amino groups (transamination)

Amino Acids of the Human Body

TABLE 6.1 Amino Acids of the Human Body

Essential Amino Acids	Nonessential Amino Acids
These amino acids must be consumed in the diet.	*These amino acids can be manufactured by the body.*
Histidine	Alanine
Isoleucine	Arginine
Leucine	Asparagine
Lysine	Aspartic acid
Methionine	Cysteine
Phenylalanine	Glutamic acid
Threonine	Glutamine
Tryptophan	Glycine
Valine	Proline
	Serine
	Tyrosine

Table 6.1

How Are Proteins Made?

Transcription: use of the genetic information in DNA to make RNA

- mRNA copies the genetic information and carries it to the ribosome

Translation: conversion of genetic information in RNA to assemble amino acids in the proper sequence to synthesize a protein on the ribosome

How Are Proteins Made?

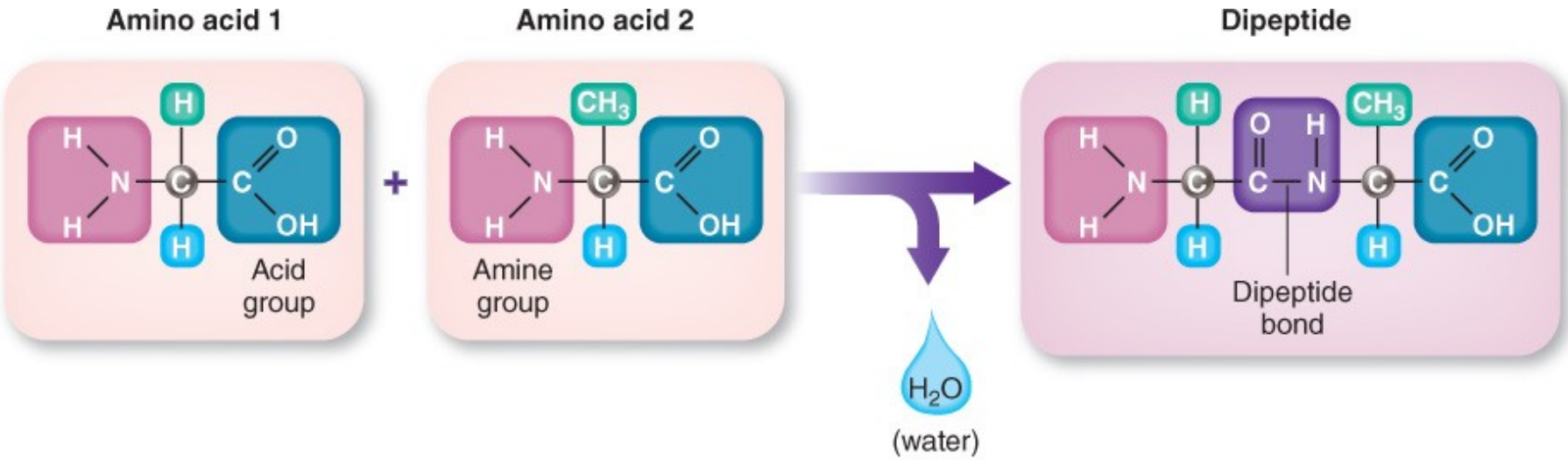
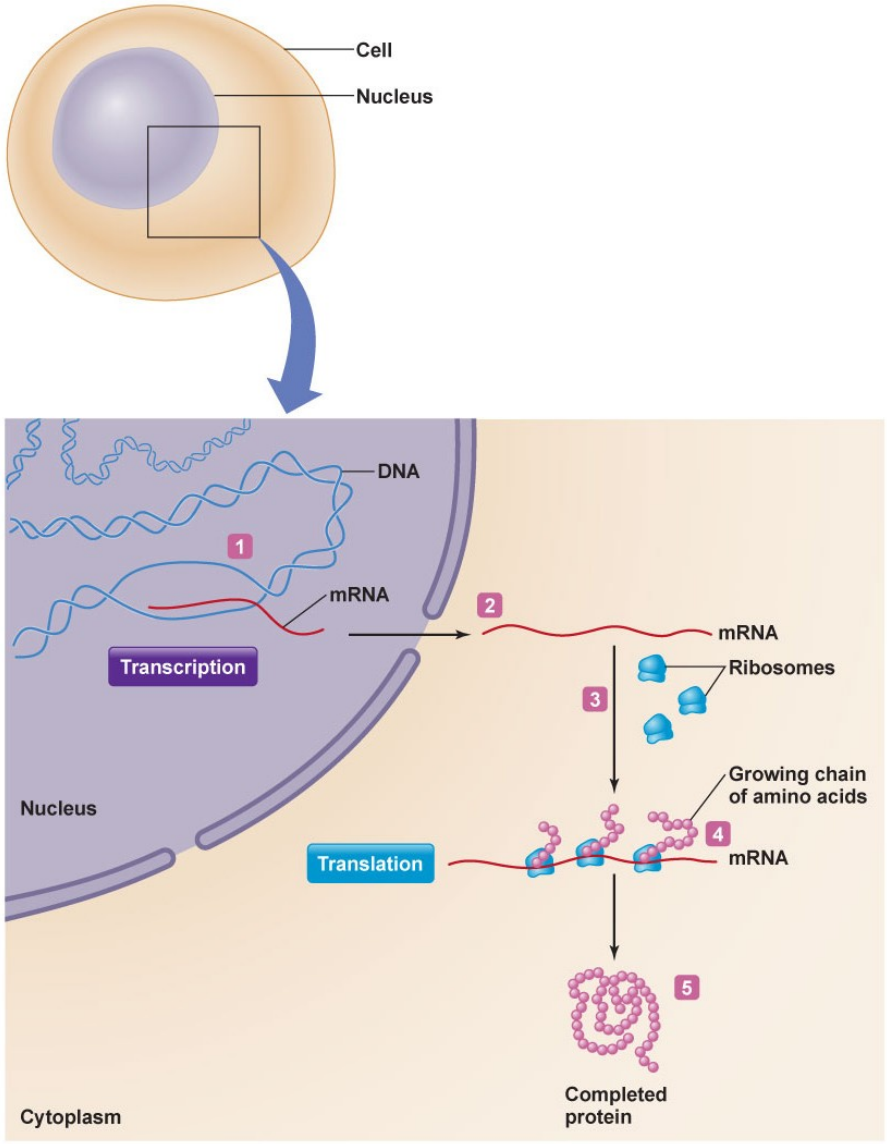


Figure 6.3 Amino acid bonding. Two amino acids join together to form a dipeptide. By combining multiple amino acids, proteins are made.

Figure 6.3

Gene Expression



1. Part of the DNA unwinds, and a section of its genetic code is transcribed to the mRNA inside the nucleus.
2. The mRNA leaves the nucleus via a nuclear pore and travels to the cytoplasm.
3. Once the mRNA reaches the cytoplasm, it binds to a ribosome. The code on the mRNA is translated into the instructions for a specific order of amino acids.
4. Amino acids are added to the growing amino acid chain, and eventually a complete protein is produced.
5. Once the synthesis of the new protein is complete, the protein is released from the ribosome. The protein may go through further modifications in the cell, or can be functional in its current state.

Figure 6.4

Protein Turnover: Synthesis and Breakdown

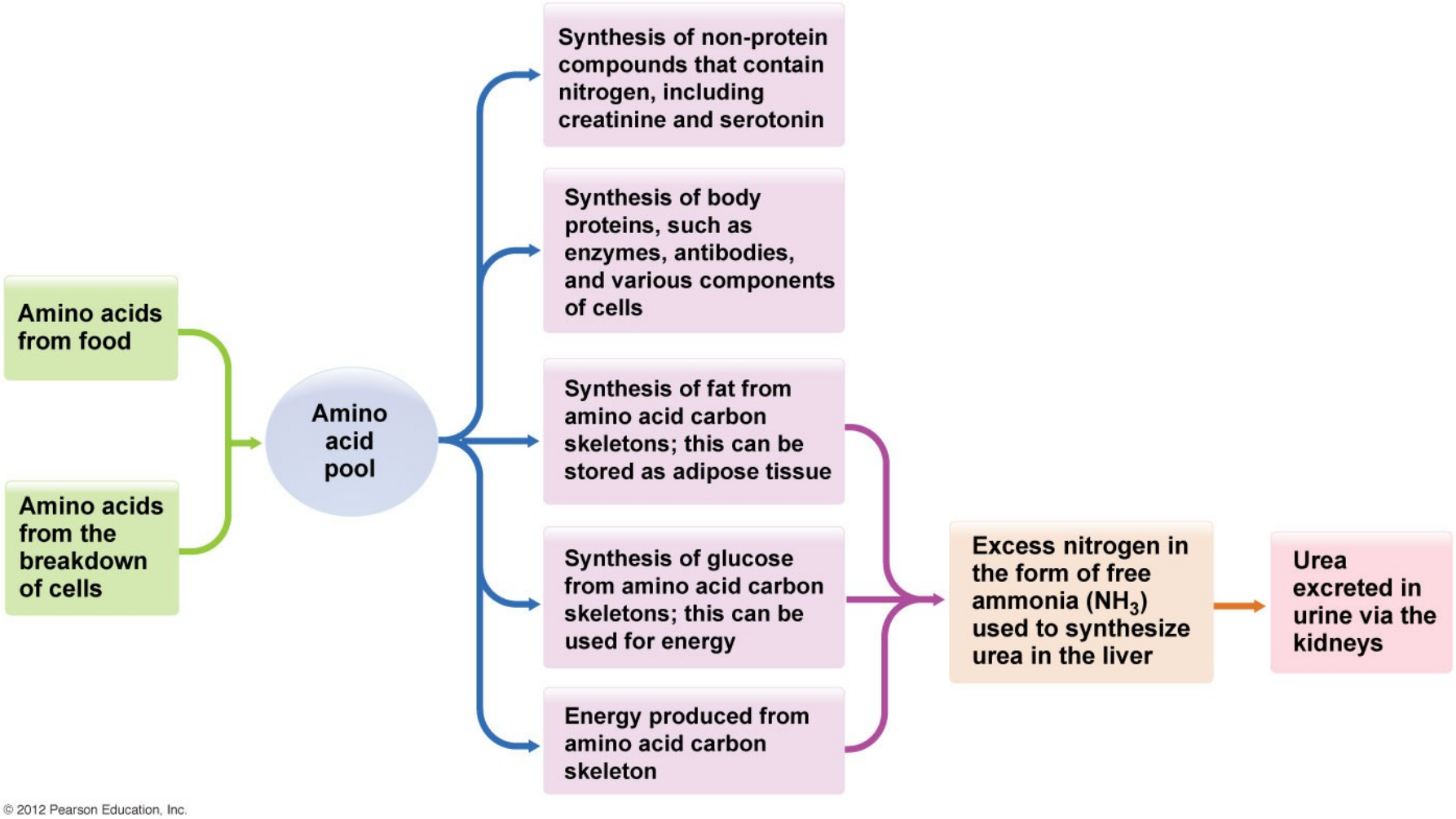


Figure 6.5

Protein Organization Determines Function

Protein structure has 4 levels

- Primary structure
  - Sequential order of amino acids
- Secondary structure
  - Spiral shape due to chemical bonding between the amino acids
- Tertiary and quaternary structure
  - Further folding into a unique 3-dimensional shape that may be globular or fibrous

Levels of Protein Structure

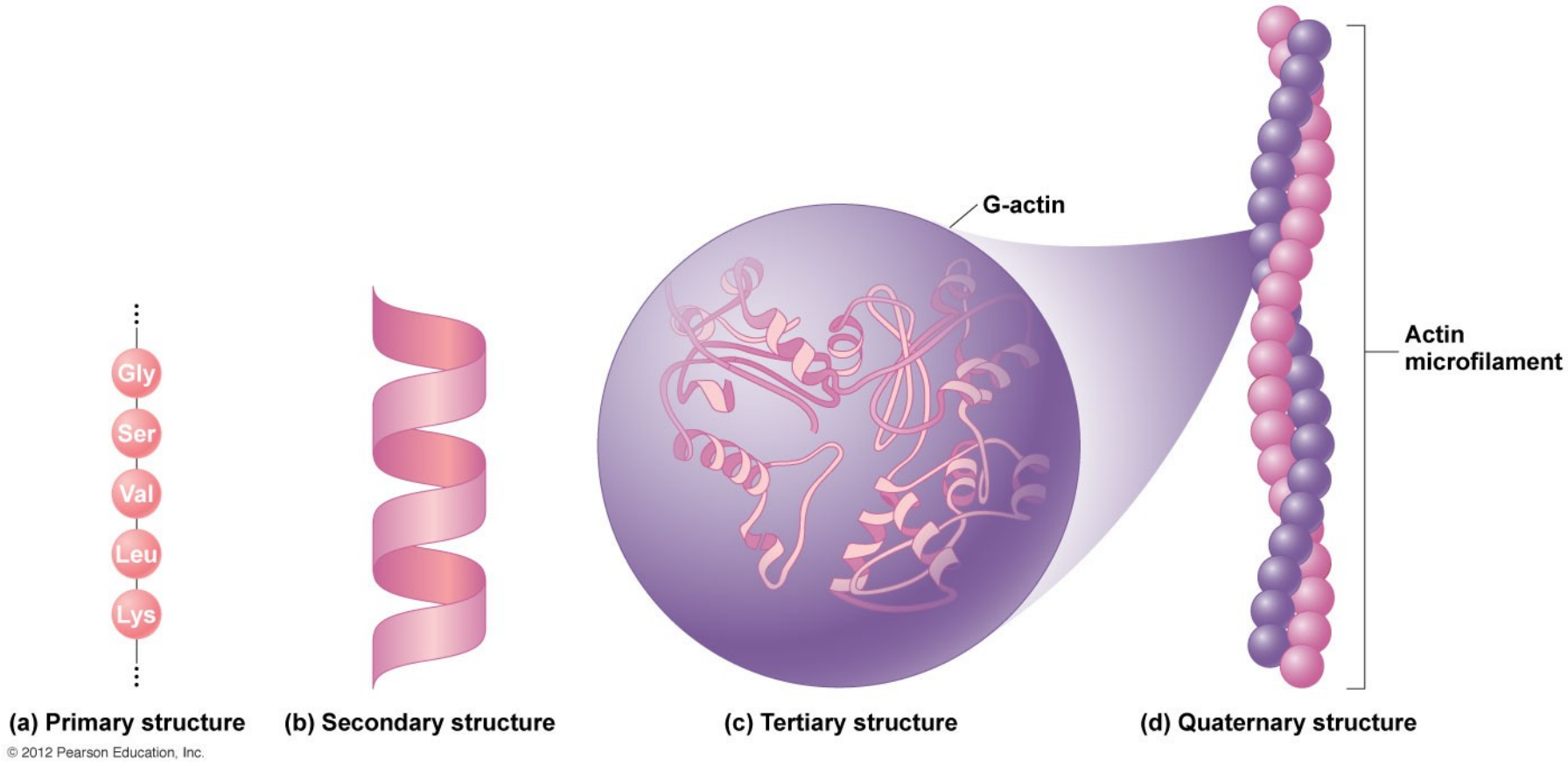


Figure 6.6

Protein Function

Proteins lose shape (denaturation) when subjected to

- Heat
- Acids and bases
- Heavy metals
- Alcohol
- Other damaging substances

Denaturation results in an irreversible loss in protein function

Protein Shape Determines Function

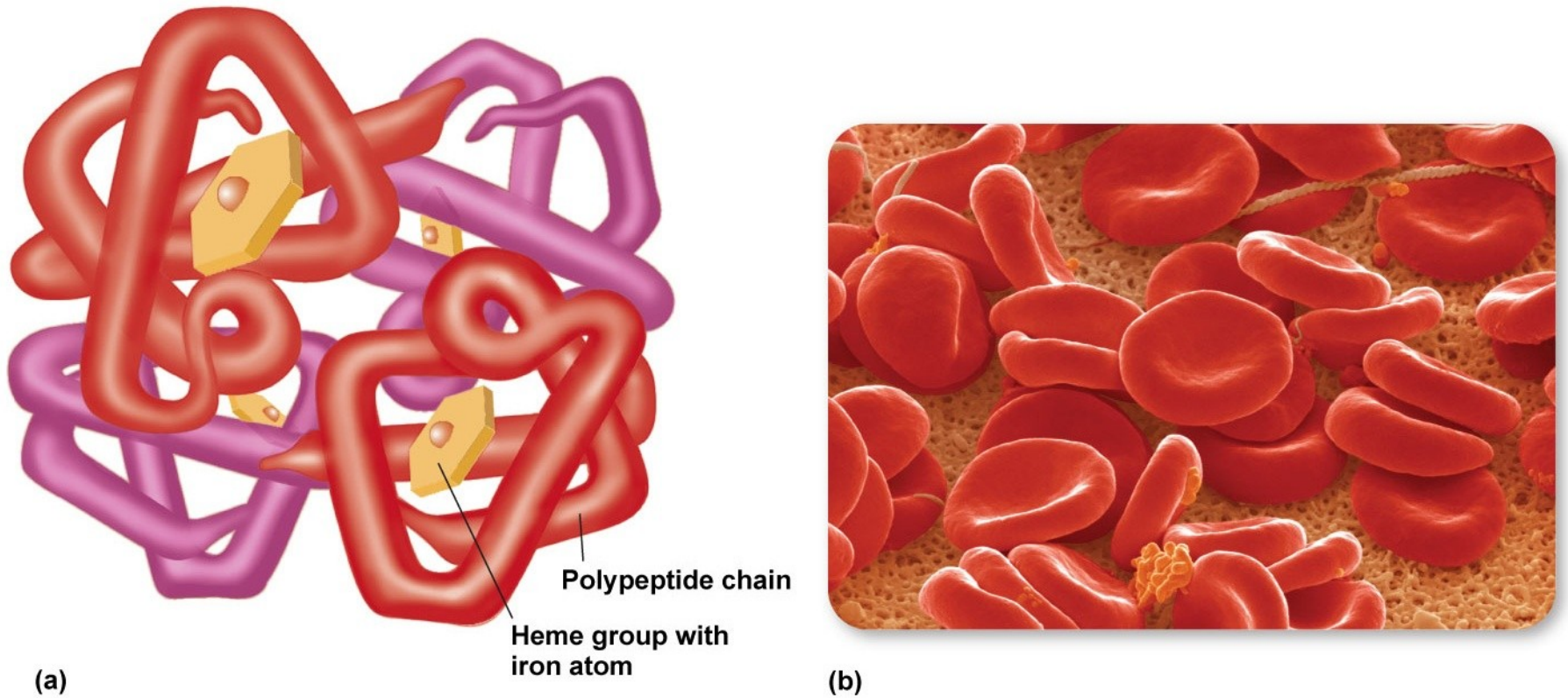


Figure 6.7

Proteins in the Diet

Incomplete protein: does not contain all essential amino acids in sufficient quantities

- Growth and health are compromised
- Considered a “low-quality” protein

Complete protein: contains sufficient amounts of all 9 essential amino acids

- Considered a “high-quality” protein

Proteins in the Diet

Mutual supplementation: combining 2 incomplete proteins to make a complete protein

Complementary proteins: 2 protein sources that together supply all 9 essential amino acids

- Example: beans and rice

Complementary Food Combinations

Food with limiting amino acid	+	Foods high in limiting amino acid	→	Complementary food combination
Legumes: limited in methionine and cysteine	+	Grains Nuts and Seeds	→	· Red beans and rice · Rice and lentils · Rice and black-eyed peas · Hummus (garbanzo beans and sesame seeds)
Grains: limited in lysine	+	Legumes	→	· Peanut butter and bread · Barley and lentil soup · Corn tortilla and beans
Vegetables: limited in lysine, methionine, and cysteine	+	Legumes (lysine) Grains (methionine and cysteine) Nuts and Seeds (methionine and cysteine)	→	· Tofu and broccoli with almonds · Spinach salad with pine nuts and kidney beans
Nuts and Seeds: limited in lysine and isoleucine	+	Legumes	→	· Lentil soup with slivered almonds · Sesame seeds with mixed bean salad

Figure 6.8

Why Do We Need Proteins?

- Cell growth, repair, and maintenance
- Enzymes
- Hormones
- Fluid and electrolyte balance
- pH balance
- Antibodies to protect against disease
- Energy source

Digestion of Proteins

Digestion of proteins begins in the stomach

- Hydrochloric acid breaks down protein structure (denatures)
- Hydrochloric acid activates pepsin

Pepsin: an enzyme that breaks down proteins into short polypeptides and amino acids

How Do We Break Down Proteins?

Digestion of proteins continues in the small intestine

- Pancreatic enzymes called proteases complete the digestion of proteins into single amino acids
- Indigestible proteins are of lower quality for nutrition

Protein Digestion

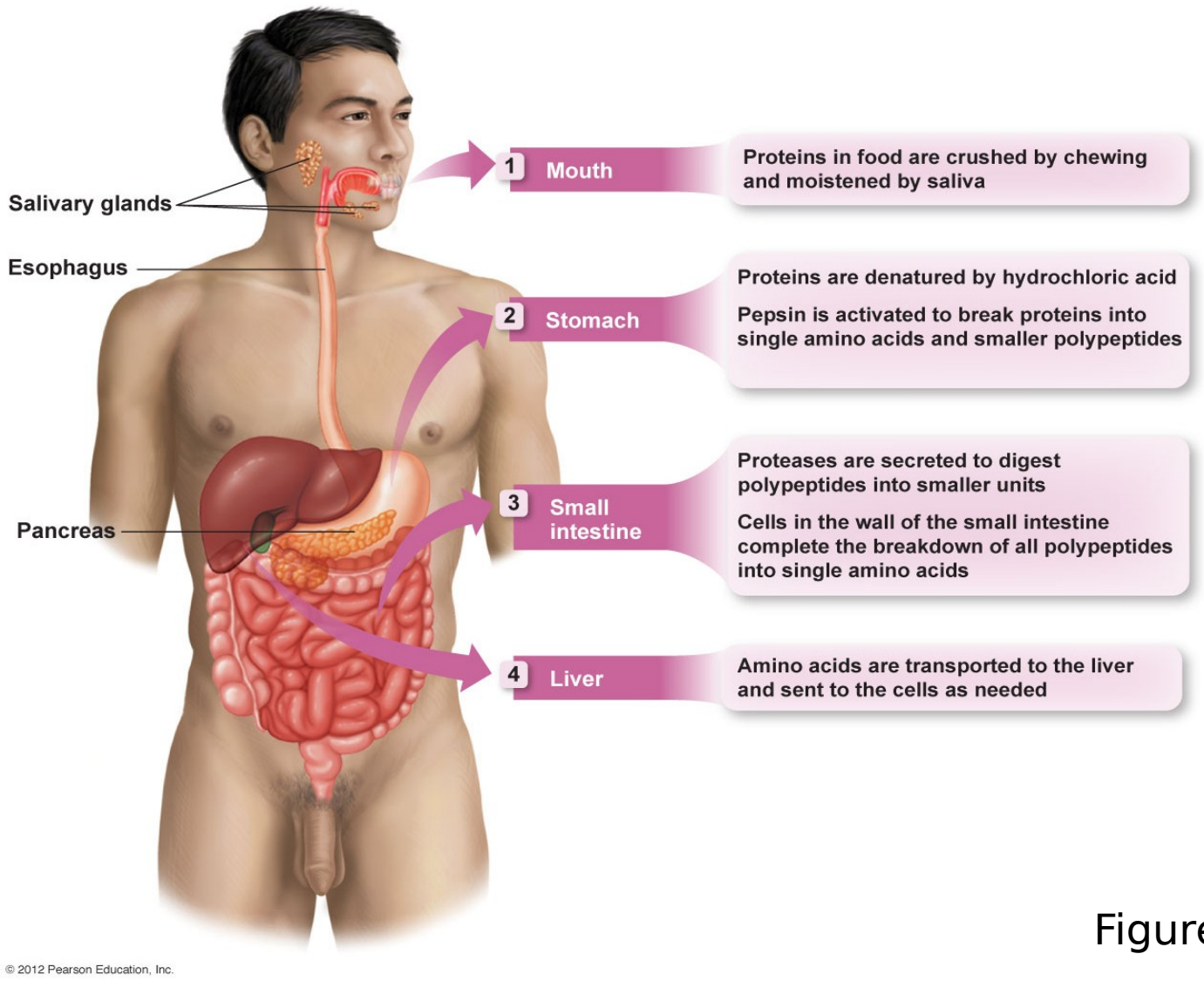


Figure 6.12

Protein Quality

1. The quantity of essential amino acids in a protein determines its quality

2. Protein digestibility

   Animal protein sources (meat, dairy), soy products, and legumes are highly digestible

   Grains and vegetable proteins are less digestible

How Much Protein Should We Eat?

People who require more protein include

- Children
- Adolescents
- Pregnant or lactating women
- Athletes and active people
- Vegetarians

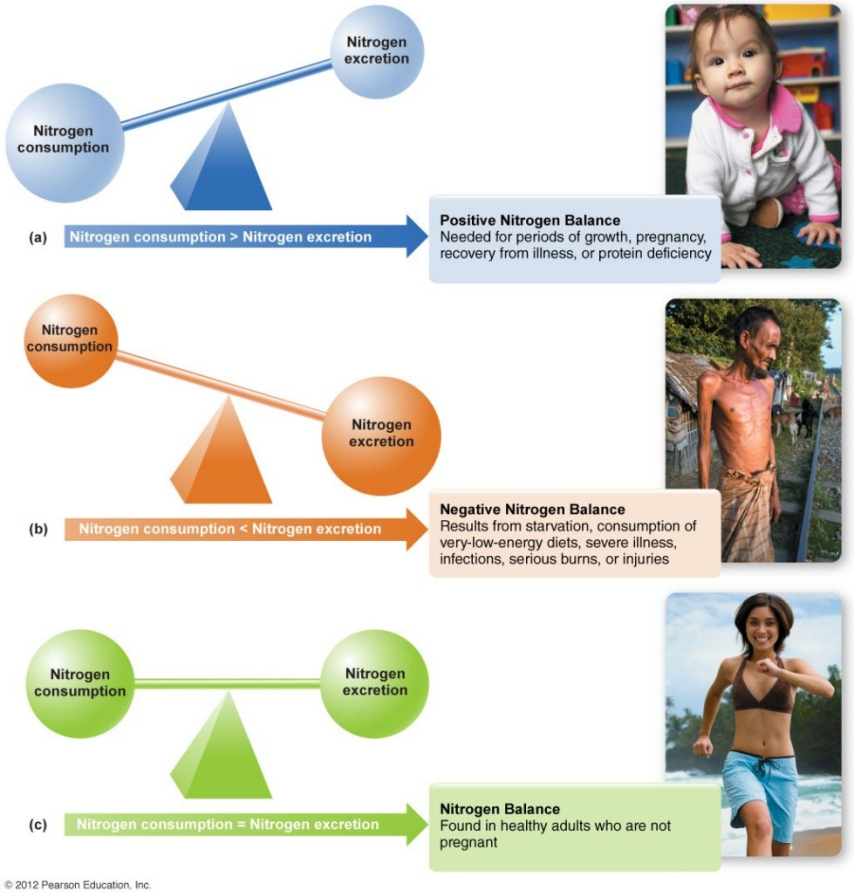
How Much Protein Should We Eat?

Recommended Dietary Allowance (RDA)

- 0.8 grams of protein per kilogram of body weight/day
- 10–35% of total energy intake should be from protein

- CCHS 2007 results show that the average protein intake among adults is 16.8% of energy

Nitrogen Balance



Nitrogen balance describes the relationship between how much nitrogen (or protein) we consume and excrete each day

Figure 6.13

How Much Protein Should We Eat?

TABLE 6.2 Recommended Protein Intakes

Group	Protein Intake (grams per kilogram* body weight per day)
Most adults†	0.8
Nonvegetarian endurance athletes‡	1.2 to 1.4
Nonvegetarian strength athletes‡	1.2 to 1.7
Vegetarian endurance athletes‡	1.3 to 1.5
Vegetarian strength athletes‡	1.3 to 1.8

*To convert body weight to kilograms, divide weight in pounds by 2.2.
Weight (lb)/2.2 = Weight (kg)
Weight (kg) × protein recommendation (g/kg body weight/day) = protein intake (g/day)
†Food and Nutrition Board, Institute of Medicine. 2002. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)*, pp. 465–608. Washington, DC: National Academies Press.
‡American College of Sports Medicine, American Dietetic Association, and Dietitians of Canada. 2009. Joint Position Statement. Nutrition and athletic performance. *Med. Sci. Sports Exerc.* 41(3):709–731.

Table 6.2

How Much Protein Should We Eat?

Most Canadians meet or exceed the RDA for dietary protein

Many foods besides meat can be good protein sources, including dairy products, legumes, eggs, nuts, and whole grains

“New” food sources of protein include quorn, quinoa, and amaranth

Protein Content of Common Foods

TABLE 6.3 Protein Content of Commonly Consumed Foods

Food	Serving Size	Protein (g)	Food	Serving Size	Protein (g)
Beef:			*Beans:*		
Ground, lean, baked (15% fat)	3 oz	22	Refried	1/2 cup	7
Prime rib, broiled (1/8-in. fat)	3 oz	18	Kidney, red	1/2 cup	7.7
Top sirloin, broiled (1/8-in. fat)	3 oz	23	Black	1/2 cup	7
Poultry:			*Nuts:*		
Chicken breast, broiled, no skin (bone removed)	1/2 breast	29	Peanuts, dry roasted	1 oz	6.7
Chicken thigh, bone and skin removed	1 thigh	13.5	Peanut butter, creamy	2 tbsp.	8
Turkey breast, roasted, Louis Rich	3 oz	15	Almonds, blanched	1 oz	6
Seafood:			*Cereals, Grains, and Breads:*		
Cod, cooked	3 oz	19	Oatmeal, quick instant	1 cup	5.4
Salmon, Chinook, baked	3 oz	22	Cheerios	1 cup	3
Shrimp, steamed	3 oz	18	Grape-Nuts	1/2 cup	6
Tuna, in water, drained	3 oz	22	Raisin Bran	1 cup	5
Pork:			Brown rice, cooked	1 cup	5
Pork loin chop, broiled	3 oz	25	Whole-wheat bread	1 slice	2.7
Ham, roasted, lean	3 oz	20	Bagel, 3 1/2 -in.-diameter	1 each	7
Dairy:			*Vegetables:*		
Whole milk (3.3% fat)	8 fl. oz	7.9	Carrots, raw (7.5 × 1 1/8 in.)	1 each	0.7
1% milk	8 fl. oz	8.5	Broccoli, raw, chopped	1 cup	2.6
Skim milk	8 fl. oz	8.8	Collards, cooked from frozen	1 cup	5
Low-fat, plain yogurt	8 fl. oz	13	Spinach, raw	1 cup	0.9
American cheese, processed	1 oz	6			
Cottage cheese, low-fat (2%)	1 cup	27			
Soy Products:					
Tofu	3.3 oz	7			
Tempeh, cooked	3.3 oz	18			
Soy milk beverage	1 cup	7			

Source: Values obtained from U.S. Department of Agriculture, Agricultural Research Service. 2009. USDA National Nutrient Database for Standard Reference, Release 22. Nutrient Data Laboratory Home Page, www.ars.usda.gov/ba/bhnrc/ndl.

Table 6.3

Can Vegetarian Diets Provide Protein?

Vegetarianism: a diet that does not include meat (including poultry) or seafood, or products containing those foods

- There are many versions of vegetarianism
- There are many reasons to adopt a vegetarian diet
- 4% of Canadian adults follow vegetarian diets

Types of Vegetarian Diets

TABLE 6.4 Terms and Definitions of a Vegetarian Diet

Type of Diet	Foods Consumed	Comments
Semivegetarian (also called partial vegetarian or flexitarian)	Vegetables, grains, nuts, fruits, legumes; sometimes seafood, poultry, eggs, and dairy products	Typically excludes or limit red meat; may also avoid other meats
Pescovegetarian	Similar to semivegetarian but excludes poultry	*Pesco* means "fish," the only animal source of protein in this diet
Lacto-ovo-vegetarian	Vegetables, grains, nuts, fruits, legumes, dairy products (*lacto*) and eggs (*ovo*)	Excludes animal flesh and seafood
Lacto-vegetarian	Similar to lacto-ovo-vegetarian but excludes eggs	Relies on milk and cheese for animal sources of protein
Ovovegetarian	Vegetables, grains, nuts, fruits, legumes, and eggs	Excludes dairy, flesh, and seafood products
Vegan (also called strict vegetarian)	Only plant-based foods (vegetables, grains, nuts, seeds, fruits, legumes)	May not provide adequate vitamin B_{12}, zinc, iron, or calcium
Macrobiotic diet	Vegan-type of diet; becomes progressively more strict until almost all foods are eliminated; at the extreme, only brown rice and small amounts of water or herbal tea are consumed	Taken to the extreme, can cause malnutrition and death
Fruitarian	Only raw or dried fruit, seeds, nuts, honey, and vegetable oil	Very restrictive diet; deficient in protein, calcium, zinc, iron, vitamin B_{12}, riboflavin, and other nutrients

Table 6.4

Why Vegetarianism?

People chose vegetarianism because of

- Religious reasons
- Ethical reasons
- Concerns over food safety
- Ecological reasons
- Health benefits

Health Benefits of Vegetarianism

- Lower intake of fat and total energy
- Lower blood pressure
- Reduce the risk of heart disease
- Fewer digestive problems
- Reduce the risk of some types of cancer
- Reduce the risk for kidney disease, kidney stones and gallstones

Challenges of Vegetarianism

- Vegetarian diets can be low in some vitamins and minerals (iron, calcium, zinc, vitamins D, B_2 and B_{12})
- Vegetarians must plan a balanced and adequate diet
- Soy products are an excellent protein source
- Vegetarians should include complementary proteins
- Vegetarians should use a Vegetarian Food Guide to design the diet

Nutrients of Concern for Vegetarians

TABLE 6.5 Nutrients of Concern in a Vegan Diet

Nutrient	Functions	Non-Meat/Non-Dairy Food Sources
Vitamin B_{12}	Assists with DNA synthesis; protection and growth of nerve fibres	Vitamin B_{12}–fortified cereals, yeast, soy products, and other meat analogs; vitamin B_{12} supplements
Vitamin D	Promotes bone growth	Vitamin D–fortified cereals, margarines, and soy products; adequate exposure to sunlight; supplementation may be necessary for those who do not get adequate exposure to sunlight
Riboflavin (vitamin B_2)	Promotes release of energy; supports normal vision and skin health	Whole and enriched grains, green leafy vegetables, mushrooms, beans, nuts, and seeds
Iron	Assists with oxygen transport; involved in making amino acids and hormones	Whole-grain products, prune juice, dried fruits, beans, nuts, seeds, and leafy vegetables (such as spinach)
Calcium	Maintains bone health; assists with muscle contraction, blood pressure, and nerve transmission	Fortified soy milk and tofu, almonds, dry beans, leafy vegetables, and calcium-fortified juices
Zinc	Assists with DNA and RNA synthesis, immune function, and growth	Whole-grain products, wheat germ, beans, nuts, and seeds

Table 6.5

Can You Eat Too Much Protein?

The risks of too much dietary protein may include

- High cholesterol and heart disease
  - Diets high in protein from animal sources are associated with high cholesterol due to high saturated fat content
- Possible bone loss
  - High-protein diets may cause excess calcium excretion, leading to bone loss

Can You Eat Too Much Protein?

The risks of too much protein may include

- Kidney disease
  - High-protein diets are associated with an increased risk of kidney disease, especially for people who may be susceptible to kidney disease
  - People with diabetes have increased rates of kidney disease

Protein-Energy Malnutrition (PEM)

Protein-energy malnutrition: a disorder caused by inadequate intake of protein and energy

There are 2 common, serious forms

- Marasmus
- Kwashiorkor

Protein-Energy Malnutrition (PEM)

Marasmus: disease resulting from grossly inadequate intakes of protein, energy, and other nutrients

Marasmus symptoms include

- Severe wasting of muscle tissue
- Stunted physical growth
- Stunted brain development
- Anemia
- Severely weakened immune system

Protein-Energy Malnutrition (PEM)

Kwashiorkor: disease resulting from extremely low protein intake

Kwashiorkor symptoms include

- Some weight loss and muscle wasting
- Edema resulting in distention of the belly
- Retarded growth and development

Kwashiorkor is often seen in children in developing countries, but can also be seen in Canada and the US

Protein-Energy Malnutrition (PEM)

PEM can affect children and adults in all countries

In Canada

- Those in poverty in inner cities or isolated rural areas
- Elderly (living alone)
- Homeless
- People with eating disorders
- Drug or alcohol addiction
- People living with AIDS or cancer

In Depth: Vitamins and Minerals

Macronutrients

Carbohydrates, fats, proteins: these nutrients

- Provide energy
- Are required in relatively large amounts

In Depth: Vitamins and Minerals

Micronutrients

- Vitamins and minerals
- Do not supply energy
- Are required in relatively small amounts
- Assist with body functions (e.g., energy metabolism, maintenance of healthy cells and tissues)

Vitamins

- Carbon-containing compounds
- 13 are essential
- 9 are soluble in water
- 4 are soluble in fat
- Humans synthesize only small amounts of vitamins D and K

Fat-Soluble Vitamins

Characteristics of fat-soluble vitamins (A, D, E, K)

- Large storage capability
- Toxicity is possible
- Deficiency symptoms may take many months to develop
- May occur in numerous chemical forms

Fat-Soluble Vitamins

TABLE 1 Fat-Soluble Vitamins

Vitamin Name	Primary Functions	Recommended Intake*	Reliable Food Sources	Toxicity/Deficiency Symptoms
A (retinol, retinal, retinoic acid)	Required for ability of eyes to adjust to changes in light Protects colour vision Assists cell differentiation Required for sperm production in men and fertilization in women Contributes to healthy bone Contributes to healthy immune system	RDA: Men = 900 µg Women = 700 µg UL = 3000 µg/day	Preformed retinol: beef and chicken liver, egg yolks, milk Carotenoid precursors: spinach, carrots, mango, apricots, cantaloupe, pumpkin, yams	*Toxicity:* fatigue; bone and joint pain; spontaneous abortion and birth defects of fetuses in pregnant women; nausea and diarrhea; liver damage; nervous system damage; blurred vision; hair loss; skin disorders *Deficiency:* night blindness, xerophthalmia; impaired growth, immunity, and reproductive function
D (cholecalciferol)	Regulates blood calcium levels Maintains bone health Assists cell differentiation	RDA Adults aged 19 to 70 years = 15 µg /day Adults aged >70 years = 20 µg /day UL = 100 µg/day	Canned salmon and mackerel, milk, fortified cereals	*Toxicity:* hypercalcemia *Deficiency:* rickets in children; osteomalacia and/or osteoporosis in adults
E (tocopherol)	As a powerful antioxidant, protects cell membranes, polyunsaturated fatty acids, and vitamin A from oxidation Protects white blood cells Enhances immune function Improves absorption of vitamin A	RDA: Men = 15 mg/day Women = 15 mg/day UL = 1000 mg/day	Sunflower seeds, almonds, vegetable oils, fortified cereals	*Toxicity:* rare *Deficiency:* hemolytic anemia; impairment of nerve, muscle, and immune function
K (phylloquinone, menaquinone, menadione)	Serves as a coenzyme during production of specific proteins that assist in blood coagulation and bone metabolism	AI: Men = 120 µg/day Women = 90 µg/day	Kale, spinach, turnip greens, Brussels sprouts	*Toxicity:* none known *Deficiency:* impaired blood clotting; possible effect on bone health

*Abbreviations: RDA, Recommended Dietary Allowance; UL, upper limit; AI, Adequate Intake.

Table 1 In Depth

Water-Soluble Vitamins

Characteristics of water-soluble vitamins (B-complex and C)

- Minimal storage capability
- Toxicity is rare
- Deficiency symptoms occur quickly
- Excreted in urine when tissues are saturated

Water-Soluble Vitamins

TABLE 2 Water-Soluble Vitamins

Vitamin Name	Primary Functions	Recommended Intake*	Reliable Food Sources	Toxicity/Deficiency Symptoms
Thiamin (vitamin B_1)	Required as enzyme cofactor for carbohydrate and amino acid metabolism	RDA: Men = 1.2 mg/day Women = 1.1 mg/day	Pork, fortified cereals, enriched rice and pasta, peas, tuna, legumes	*Toxicity:* none known *Deficiency:* beriberi; fatigue, apathy, decreased memory, confusion, irritability, muscle weakness
Riboflavin (vitamin B_2)	Required as enzyme cofactor for carbohydrate and fat metabolism	RDA: Men = 1.3 mg/day Women = 1.1 mg/day	Beef liver, shrimp, milk and other dairy foods, fortified cereals, enriched breads and grains	*Toxicity:* none known *Deficiency:* ariboflavinosis; swollen mouth and throat; seborrheic dermatitis; anemia
Niacin, nicotinamide, nicotinic acid	Required for carbohydrate and fat metabolism Plays role in DNA replication and repair and cell differentiation	RDA: Men = 16 mg/day Women = 14 mg/day UL = 35 mg/day	Beef liver, most cuts of meat/fish/poultry, fortified cereals, enriched breads and grains, canned tomato products	*Toxicity:* flushing, liver damage, glucose intolerance, blurred vision differentiation *Deficiency:* pellagra; vomiting, constipation, or diarrhea; apathy
Pyridoxine, pyridoxal, pyridoxamine (vitamin B_6)	Required as enzyme cofactor for carbohydrate and amino acid metabolism Assists synthesis of blood cells	RDA: Men and women aged 19 to 50 = 1.3 mg/day Men aged >50 and over = 1.7 mg/day Women aged >50 and over = 1.5 mg/day UL = 100 mg/day	Chickpeas (garbanzo beans), most cuts of meat/fish/poultry, fortified cereals, white potatoes	*Toxicity:* nerve damage, skin lesions *Deficiency:* anemia; seborrheic dermatitis; depression, confusion, and convulsions
Folate (folic acid)	Required as enzyme cofactor for amino acid metabolism Required for DNA synthesis Involved in metabolism of homocysteine	RDA: Men = 400 µg/day Women = 400 µg/day UL = 1000 µg/day	Fortified cereals, enriched breads and grains, spinach, legumes (lentils, chickpeas, pinto beans), greens (spinach, romaine lettuce), liver	*Toxicity:* masks symptoms of vitamin B12 deficiency, specifically signs of nerve damage *Deficiency:* macrocytic anemia; neural tube defects in a developing fetus; elevated homocysteine levels
Cobalamin (vitamin B_{12})	Assists with formation of blood Required for healthy nervous system function Involved as enzyme cofactor in metabolism of homocysteine	RDA: Men = 2.4 µg/day Women = 2.4 µg/day	Shellfish, all cuts of meat/fish/poultry, milk and other dairy foods, fortified cereals	*Toxicity:* none known *Deficiency:* pernicious anemia; tingling and numbness of extremities; nerve damage; memory loss, disorientation, and dementia
Pantothenic acid	Assists with fat metabolism	AI: Men = 5 mg/day Women = 5 mg/day	Meat/fish/poultry, shiitake mushrooms, fortified cereals, egg yolk	*Toxicity:* none known *Deficiency:* rare
Biotin	Involved as enzyme cofactor in carbohydrate, fat, and protein metabolism	RDA: Men = 30 µg/day Women = 30 µg/day	Nuts, egg yolk	*Toxicity:* none known *Deficiency:* rare
Ascorbic acid (vitamin C)	Antioxidant in extracellular fluid and lungs Regenerates oxidized vitamin E Assists with collagen synthesis Enhances immune function Assists in synthesis of hormones, neurotransmitters, and DNA Enhances iron absorption	RDA: Men = 90 mg/day Women = 75 mg/day Smokers = 35 mg more per day than RDA UL = 2000 mg	Sweet peppers, citrus fruits and juices, broccoli, strawberries, kiwi	*Toxicity:* nausea and diarrhea, nosebleeds, increased oxidative damage, increased formation of kidney stones in people with kidney disease *Deficiency:* scurvy; bone pain and fractures, depression, and anemia

*Abbreviations: RDA, Recommended Dietary Allowance; UL, upper limit; AI, Adequate Intake.

Table 2 In Depth

Minerals

General properties of minerals

- Inorganic
- Cannot be synthesized by plants or animals
- Not digested or broken down prior to absorption
- 2 classifications based on need

Major Minerals

Characteristics of major minerals

- Required in amounts of at least 100 mg/day
- 7 major minerals: sodium
  potassium
  phosphorous
  chloride
  calcium
  magnesium
  sulphur

Major Minerals

TABLE 3 Major Minerals

Mineral Name	Primary Functions	Recommended Intake*	Reliable Food Sources	Toxicity/Deficiency Symptoms
Sodium	Fluid balance Acid–base balance Transmission of nerve impulses Muscle contraction	AI: Adults = 1.5 g/day (1500 mg/day)	Table salt, pickles, most canned soups, snack foods, cured luncheon meats, canned tomato products	*Toxicity:* water retention, high blood pressure, loss of calcium *Deficiency:* muscle cramps, dizziness, fatigue, nausea, vomiting, mental confusion
Potassium	Fluid balance Transmission of nerve impulses Muscle contraction	AI: Adults = 4.7 g/day (4700 mg/day)	Most fresh fruits and vegetables: potatoes, bananas, tomato juice, orange juice, melons	*Toxicity:* muscle weakness, vomiting, irregular heartbeat *Deficiency:* muscle weakness, paralysis, mental confusion, irregular heartbeat
Phosphorus	Fluid balance Bone formation Component of ATP, which provides energy for our bodies	RDA: Adults = 700 mg/day	Milk/cheese/yogurt, soy milk and tofu, legumes (lentils, black beans), nuts (almonds, peanuts and peanut butter), poultry	*Toxicity:* muscle spasms, convulsions, low blood calcium *Deficiency:* muscle weakness, muscle damage, bone pain, dizziness
Chloride	Fluid balance Transmission of nerve impulses Component of stomach acid (HCl) Antibacterial	AI: Adults = 2.3 g/day (2300 mg/day)	Table salt	*Toxicity:* none known *Deficiency:* dangerous blood acid–base imbalances, irregular heartbeat
Calcium	Primary component of bone Acid–base balance Transmission of nerve impulses Muscle contraction	AI: Adults aged 19 to 50 = 1000 mg/day Adults aged > 50 = 1200 mg/day UL= 2500 mg/day	Milk/yogurt/cheese (best-absorbed form of calcium), sardines, collard greens and spinach, calcium-fortified juices	*Toxicity:* mineral imbalances, shock, kidney failure, fatigue, mental confusion *Deficiency:* osteoporosis, convulsions, heart failure
Magnesium	Component of bone Muscle contraction Assists more than 300 enzyme systems	RDA: Men aged 19 to 30 = 400 mg/day Men aged >30 = 420 mg/day Women aged 19 to 30 = 310 mg/day Women aged >30 = 320 mg/day UL = 350 mg/day	Greens (spinach, kale, collard greens), whole grains, seeds, nuts, legumes (navy and black beans)	*Toxicity:* none known *Deficiency:* low blood calcium, muscle spasms or seizures, nausea, weakness, increased risk for chronic diseases, such as heart disease, hypertension, osteoporosis, and type 2 diabetes
Sulphur	Component of certain B vitamins and amino acids Acid–base balance Detoxification in liver	No DRI	Protein-rich foods	*Toxicity:* none known *Deficiency:* none known

*Abbreviations: RDA, Recommended Dietary Allowance; UL, upper limit; AI, Adequate Intake; DRI, Dietary Reference Intake.

Table 3 In Depth

Trace Minerals

Characteristics of trace minerals

- Required in amounts of less than 100 mg/day
- Body contains less than 5 g
- 8 trace minerals: selenium
  fluoride
  iodine
  chromium
  manganese
  iron
  zinc
  copper

Trace Minerals

TABLE 4 Trace Minerals

Mineral Name	Primary Functions	Recommended Intake*	Reliable Food Sources	Toxicity/Deficiency Symptoms
Selenium	Required for carbohydrate and fat metabolism	RDA: Adults = 55 µg/day UL = 400 µg/day	Nuts, shellfish, meat/fish/poultry, whole grains	*Toxicity:* brittle hair and nails, skin rashes, nausea and vomiting, weakness, liver disease *Deficiency:* specific forms of heart disease and arthritis, impaired immune function, muscle pain and wasting, depression, hostility
Fluoride	Development and maintenance of healthy teeth and bones	RDA: Men = 4 mg/day Women = 3 mg/day UL: 2.2 mg/day for children aged 4 to 8; children aged >8 = 10 mg/day	Fish, seafood, legumes, whole grains, drinking water (variable)	*Toxicity:* fluorosis of teeth and bones *Deficiency:* dental caries, low bone density
Iodine	Synthesis of thyroid hormones Temperature regulation Reproduction and growth	RDA: Adults = 150 µg/day UL = 1100 µg/day	Iodized salt, saltwater seafood	*Toxicity:* goitre *Deficiency:* goitre, hypothyroidism, cretinism in infant of mother who is iodine deficient
Chromium	Glucose transport Metabolism of DNA and RNA Immune function and growth	AI: Men aged 19 to 50 = 35 µg/day Men aged >50 = 30 µg/day Women aged 19 to 50 = 25 µg/day Women aged >50 = 20 µg/day	Whole grains, brewer's yeast	*Toxicity:* none known *Deficiency:* elevated blood glucose and blood lipids, damage to brain and nervous system
Manganese	Assists many enzyme systems Synthesis of protein found in bone and cartilage	AI: Men = 2.3 mg/day Women = 1.8 mg/day UL = 11 mg/day for adults	Whole grains, nuts, leafy vegetables, tea	*Toxicity:* impairment of neuromuscular system *Deficiency:* impaired growth and reproductive function, reduced bone density, impaired glucose and lipid metabolism, skin rash
Iron	Component of hemoglobin in blood cells Component of myoglobin in muscle cells Assists many enzyme systems	RDA: Adult men = 8 mg/day Women aged 19 to 50 = 18 mg/day Women aged >50 = 8 mg/day	Meat/fish/poultry (best-absorbed form of iron), fortified cereals, legumes, spinach	*Toxicity:* nausea, vomiting, and diarrhea; dizziness, confusion; rapid heartbeat, organ damage, death *Deficiency:* iron-deficiency microcytic (small red blood cells), hypochromic anemia
Zinc	Assists more than 100 enzyme systems Immune system function Growth and sexual maturation Gene regulation	RDA: Men 11 = mg/day Women = 8 mg/day UL = 40 mg/day	Meat/fish/poultry (best-absorbed form of zinc), fortified cereals, legumes	*Toxicity:* nausea, vomiting, and diarrhea; headaches, depressed immune function, reduced absorption of copper *Deficiency:* growth retardation, delayed sexual maturation, eye and skin lesions, hair loss, increased incidence of illness and infection
Copper	Assists many enzyme systems Iron transport	RDA: Adults = 900 µg/day UL = 10 mg/day	Shellfish, organ meats, nuts, legumes	*Toxicity:* nausea, vomiting, and diarrhea; liver damage *Deficiency:* anemia, reduced levels of white blood cells, osteoporosis in infants and growing children

*Abbreviations: RDA, Recommended Dietary Allowance; UL, upper limit; AI, Adequate Intake.

Table 4 In Depth

Absorption of Micronutrients

Absorption depends on numerous factors

- Chemical form (e.g., absorption of heme iron from meats, fish, poultry is ~25%, whereas non-heme iron from plant products is ~3–5%)
- Numerous factors in foods bind micronutrients and prevent absorption
- Other nutrients within a meal alter absorption

Supplementation of Micronutrients

Supplementation of micronutrients is controversial

- Easier to develop toxicity with supplements
- Some may be harmful to certain subgroups of consumers
- Most minerals are better absorbed from food
- Eating a variety of foods provides many other nutrients (e.g., phytochemicals)
- Supplements may alter the balance between nutrients

Role in Disease Prevention and Treatment

Research studies have suggested a link between consumption of some micronutrients and disease

Adequate intake of these vitamins has been associated with lower disease risk

- Vitamin C and cataracts
- Vitamin D and colon cancer
- Vitamin E and complications of diabetes
- Vitamin K and osteoporosis

Role in Disease Prevention and Treatment

Adequate intake of these minerals has been associated with lower disease risk

- Calcium and hypertension
- Chromium and type 2 diabetes in older adults
- Magnesium and muscle wasting in older adults
- Selenium and certain types of cancer

Do More Micronutrients Exist?

Nutrition researchers continue to explore the possibility of other substances being essential

Vitamin-like factors (e.g., carnitine) and numerous minerals (e.g., boron, nickel, silicon) may prove to be essential in our diet