Chapter 40

Basic Principles of Animal Form and Function

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: Diverse Forms, Common Challenges

- **Anatomy** is the study of the biological form of an organism
- **Physiology** is the study of the biological functions an organism performs
- The comparative study of animals reveals that form and function are closely correlated

Fig. 40-1

Concept 40.1: Animal form and function are correlated at all levels of organization

- Size and shape affect the way an animal interacts with its environment
- Many different animal body plans have evolved and are determined by the genome

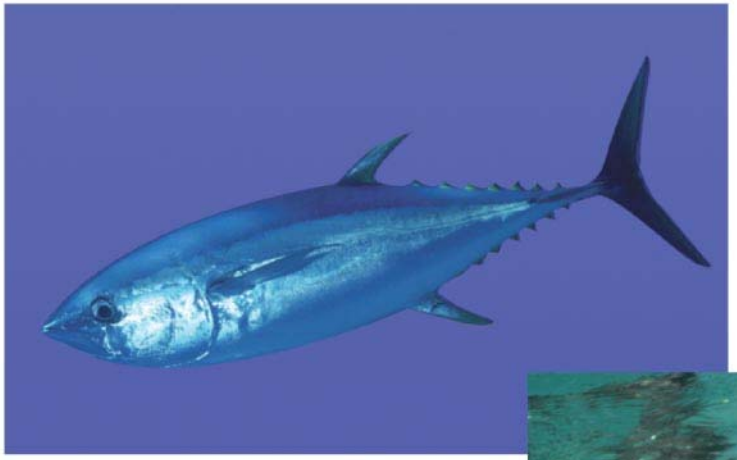
Physical Constraints on Animal Size and Shape

- The ability to perform certain actions depends on an animal's shape, size, and environment
- Evolutionary convergence reflects different species' adaptations to a similar environmental challenge
- Physical laws impose constraints on animal size and shape

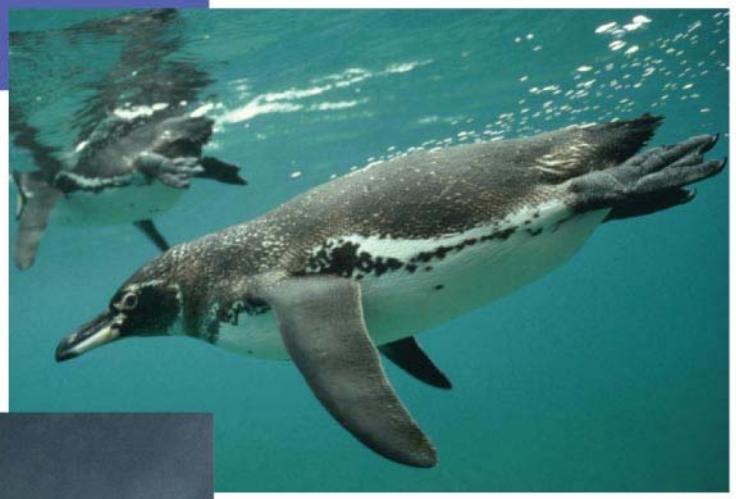
PLAY Video: Shark Eating Seal

PLAY Video: Galápagos Sea Lion

Fig. 40-2



(a) Tuna



(b) Penguin

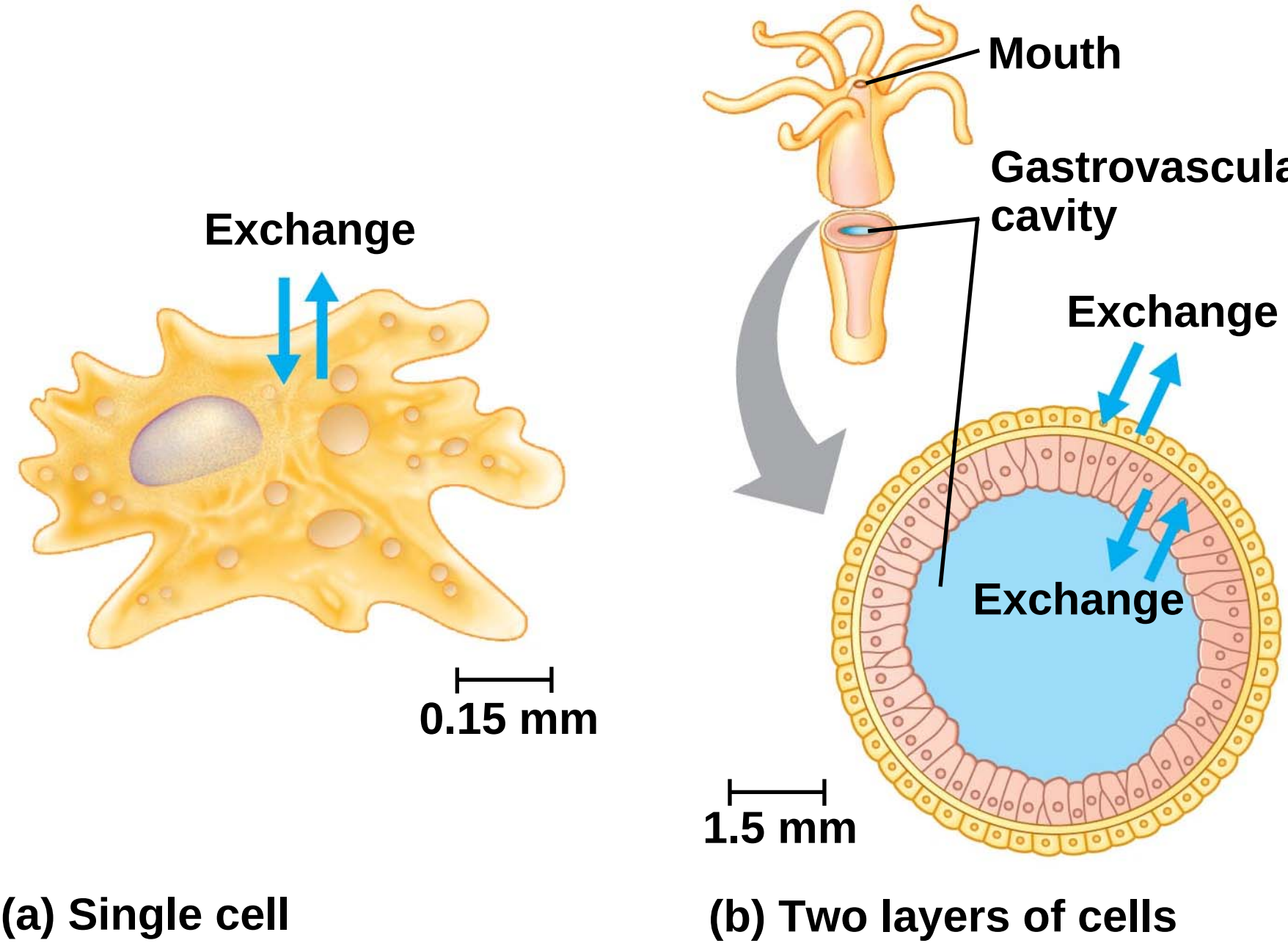
(c) Seal

Exchange with the Environment

- An animal's size and shape directly affect how it exchanges energy and materials with its surroundings
- Exchange occurs as substances dissolved in the aqueous medium diffuse and are transported across the cells' plasma membranes
- A single-celled protist living in water has a sufficient surface area of plasma membrane to service its entire volume of cytoplasm

PLAY Video: Hydra Eating Daphnia

Fig. 40-3



- Multicellular organisms with a sac body plan have body walls that are only two cells thick, facilitating diffusion of materials

- More complex organisms have highly folded internal surfaces for exchanging materials

Fig. 40-4

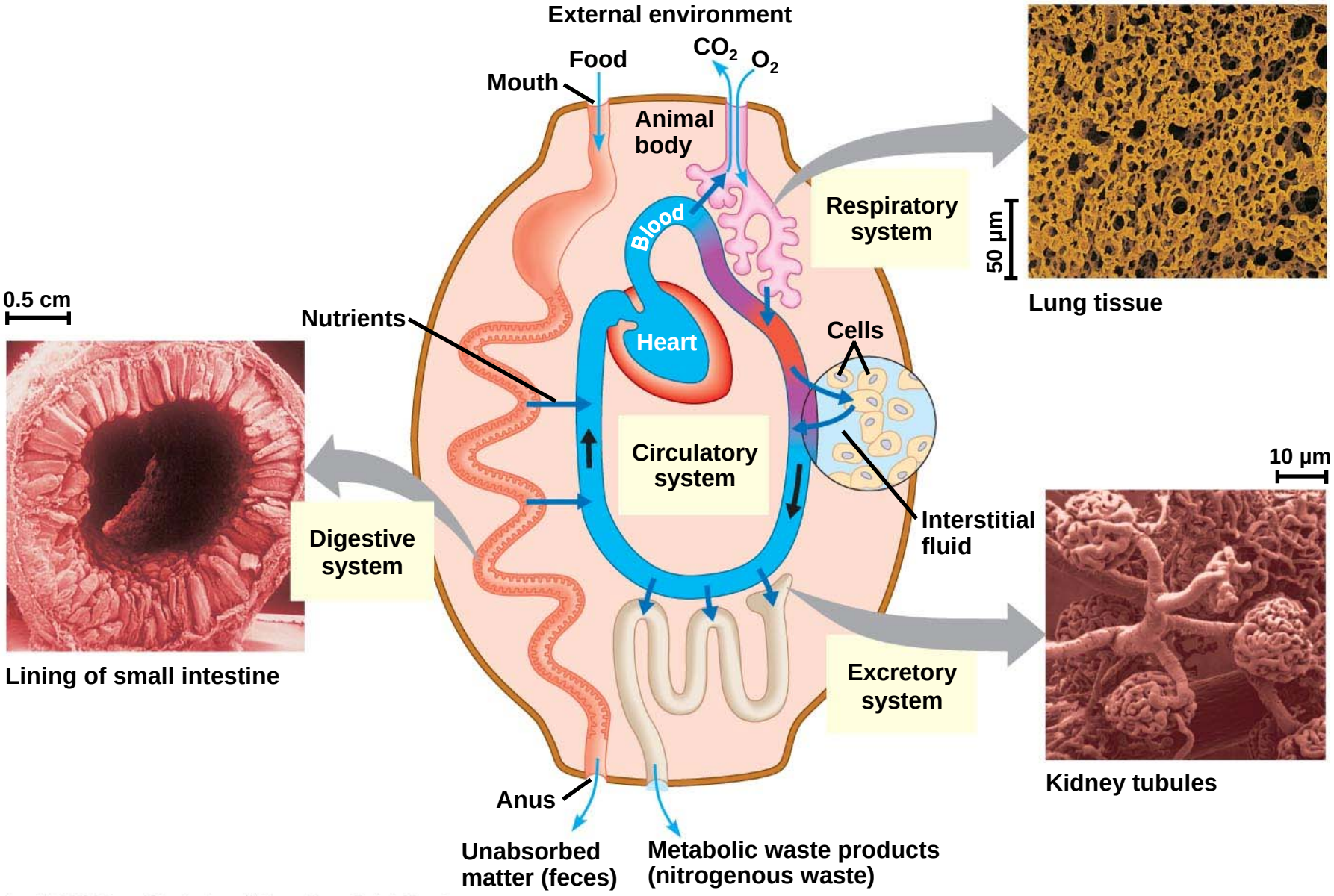


Fig. 40-4a

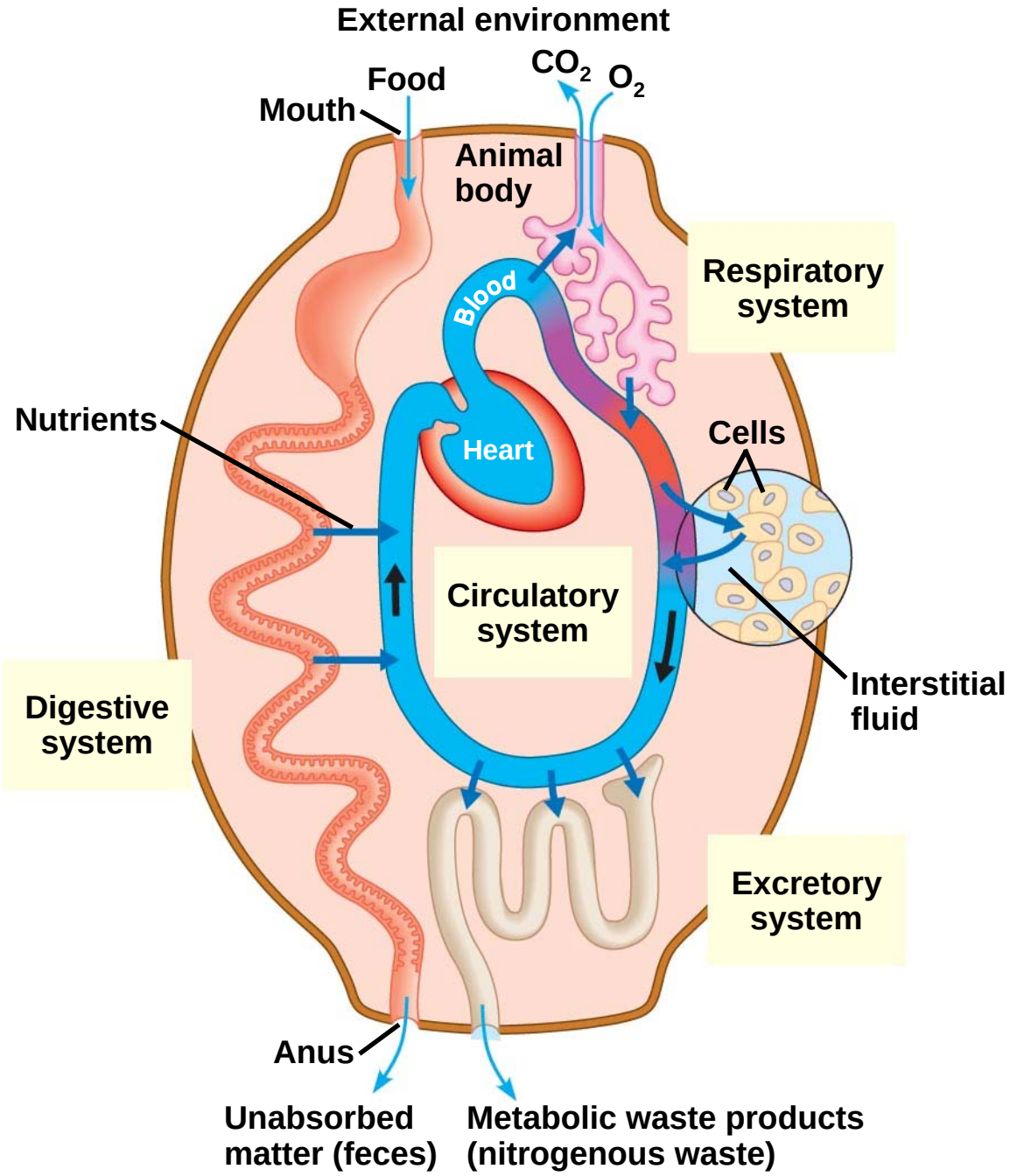
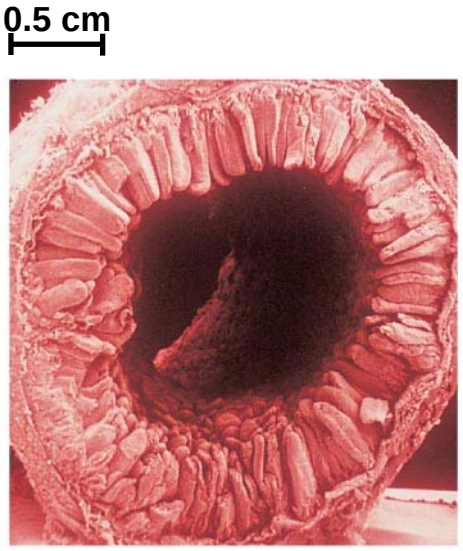
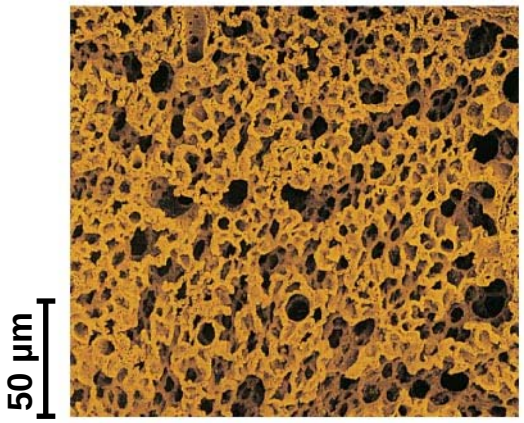


Fig. 40-4b



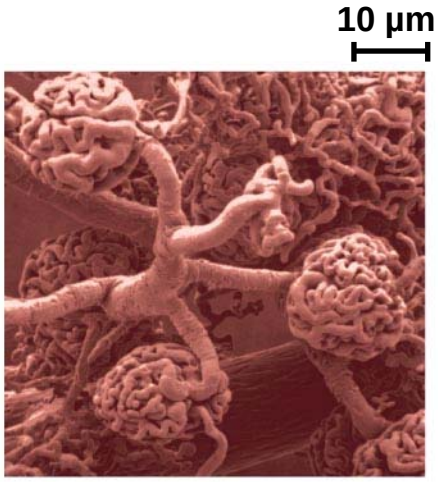
Lining of small intestine

Fig. 40-4c



Lung tissue

Fig. 40-4d



Kidney tubules

- In vertebrates, the space between cells is filled with **interstitial fluid**, which allows for the movement of material into and out of cells
- A complex body plan helps an animal in a variable environment to maintain a relatively stable internal environment

Hierarchical Organization of Body Plans

- Most animals are composed of specialized cells organized into **tissues** that have different functions
- Tissues make up **organs**, which together make up **organ systems**

Table 40-1

Table 40.1 Organ Systems: Their Main Components and Functions in Mammals

Organ System	Main Components	Main Functions
Digestive	Mouth, pharynx, esophagus, stomach, intestines, liver, pancreas, anus	Food processing (ingestion, digestion, absorption, elimination)
Circulatory	Heart, blood vessels, blood	Internal distribution of materials
Respiratory	Lungs, trachea, other breathing tubes	Gas exchange (uptake of oxygen; disposal of carbon dioxide)
Immune and lymphatic	Bone marrow, lymph nodes, thymus, spleen, lymph vessels, white blood cells	Body defense (fighting infections and cancer)
Excretory	Kidneys, ureters, urinary bladder, urethra	Disposal of metabolic wastes; regulation of osmotic balance of blood
Endocrine	Pituitary, thyroid, pancreas, adrenal, and other hormone-secreting glands	Coordination of body activities (such as digestion and metabolism)
Reproductive	Ovaries or testes, and associated organs	Reproduction
Nervous	Brain, spinal cord, nerves, sensory organs	Coordination of body activities; detection of stimuli and formulation of responses to them
Integumentary	Skin and its derivatives (such as hair, claws, skin glands)	Protection against mechanical injury, infection, drying out; thermoregulation
Skeletal	Skeleton (bones, tendons, ligaments, cartilage)	Body support, protection of internal organs, movement
Muscular	Skeletal muscles	Locomotion and other movement

Tissue Structure and Function

- Different tissues have different structures that are suited to their functions
- Tissues are classified into four main categories: epithelial, connective, muscle, and nervous

Epithelial Tissue

- **Epithelial tissue** covers the outside of the body and lines the organs and cavities within the body
- It contains cells that are closely joined
- The shape of epithelial cells may be *cuboidal* (like dice), *columnar* (like bricks on end), or *squamous* (like floor tiles)

- The arrangement of epithelial cells may be *simple* (single cell layer), *stratified* (multiple tiers of cells), or *pseudostratified* (a single layer of cells of varying length)

Fig. 40-5a

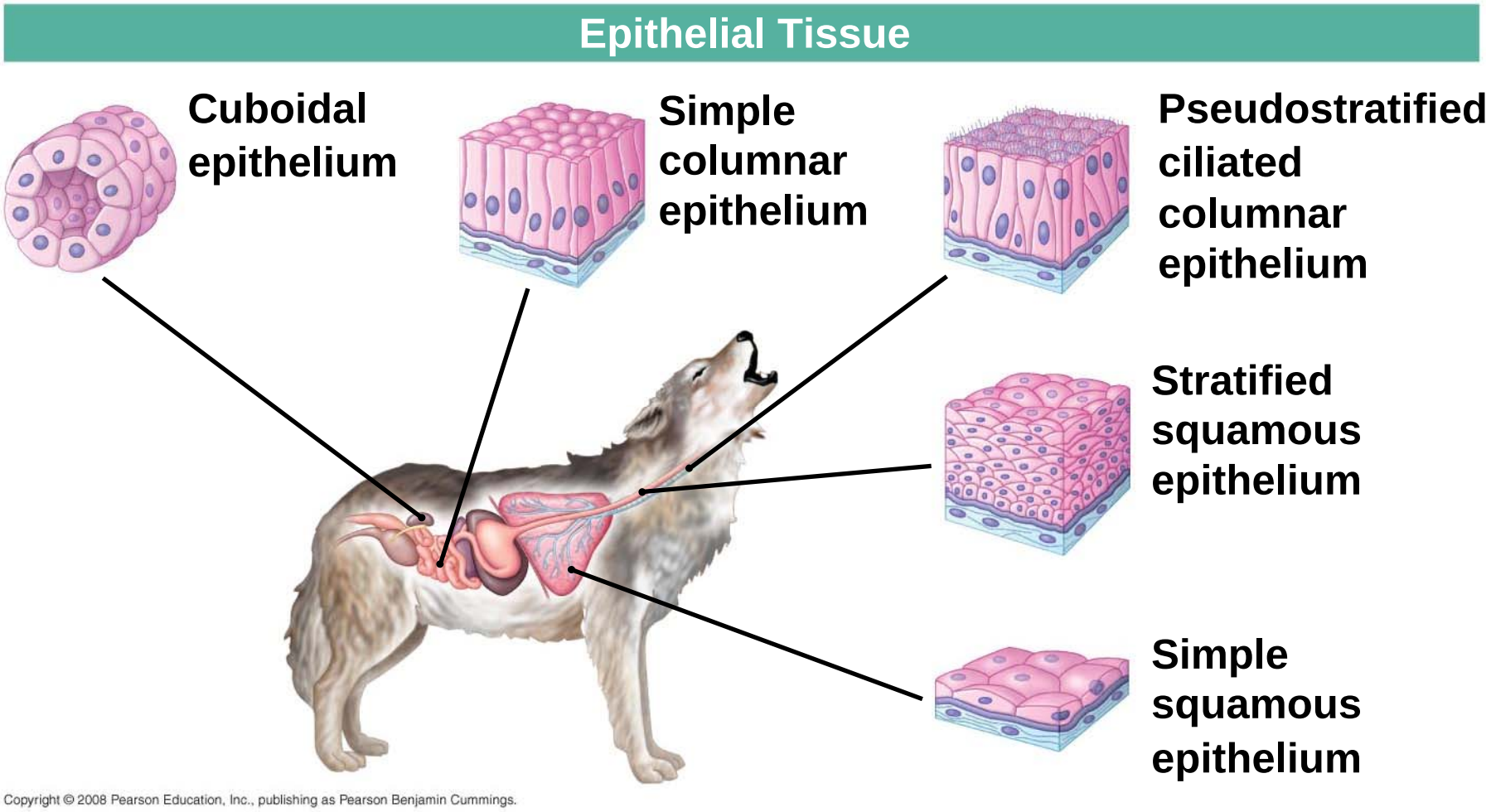
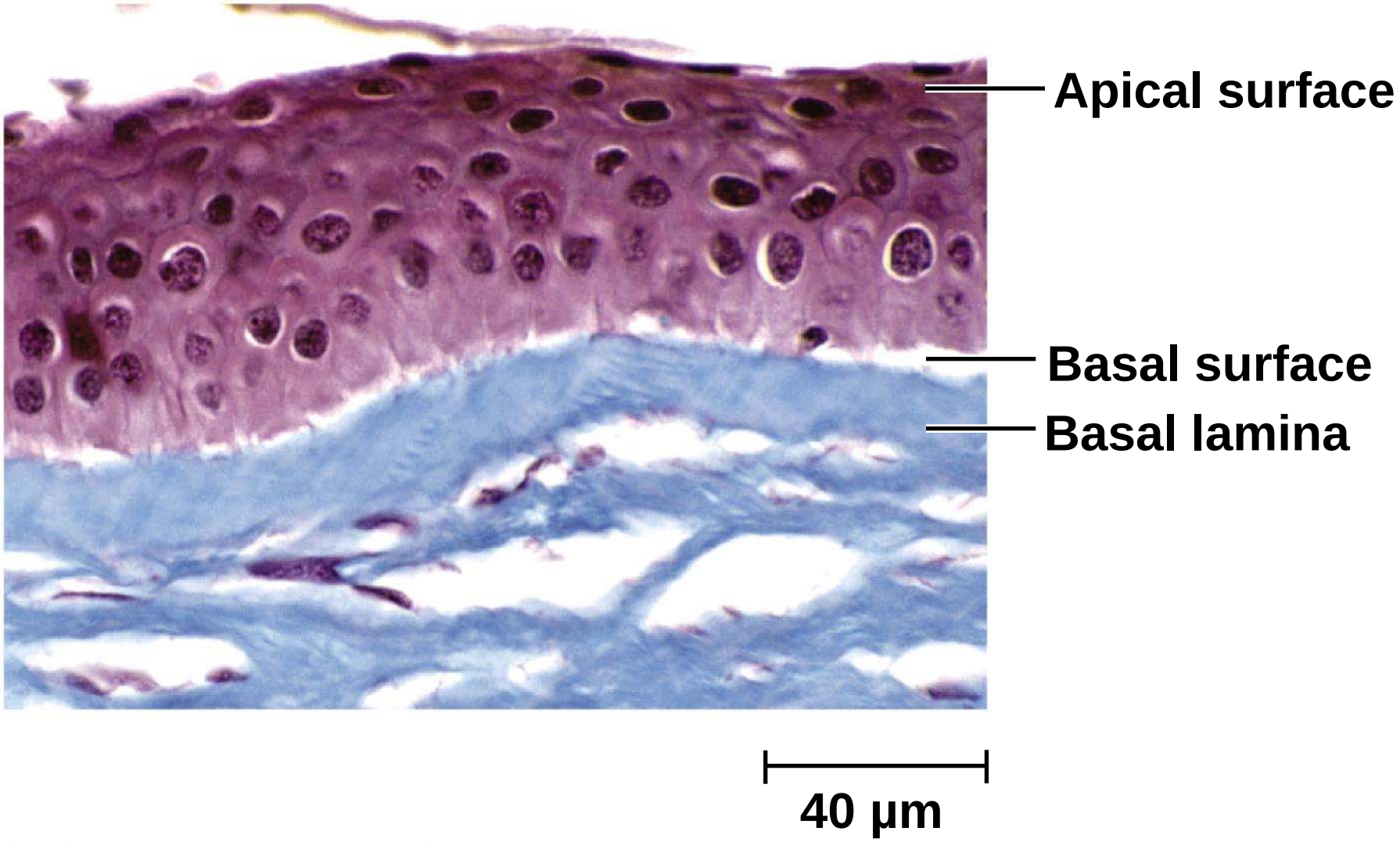


Fig. 40-5b



Connective Tissue

- **Connective tissue** mainly binds and supports other tissues
- It contains sparsely packed cells scattered throughout an extracellular matrix
- The matrix consists of fibers in a liquid, jellylike, or solid foundation

- There are three types of connective tissue fiber, all made of protein:
  - *Collagenous fibers* provide strength and flexibility
  - *Elastic fibers* stretch and snap back to their original length
  - *Reticular fibers* join connective tissue to adjacent tissues

- Connective tissue contains cells, including
  - **Fibroblasts** that secrete the protein of extracellular fibers
  - **Macrophages** that are involved in the immune system

- In vertebrates, the fibers and foundation combine to form six major types of connective tissue:
  - *Loose connective tissue* binds epithelia to underlying tissues and holds organs in place
  - **Cartilage** is a strong and flexible support material
  - *Fibrous connective tissue* is found in **tendons**, which attach muscles to bones, and **ligaments**, which connect bones at joints

- **Adipose tissue** stores fat for insulation and fuel
- **Blood** is composed of blood cells and cell fragments in blood plasma
- **Bone** is mineralized and forms the skeleton

Fig. 40-5c

Connective Tissue

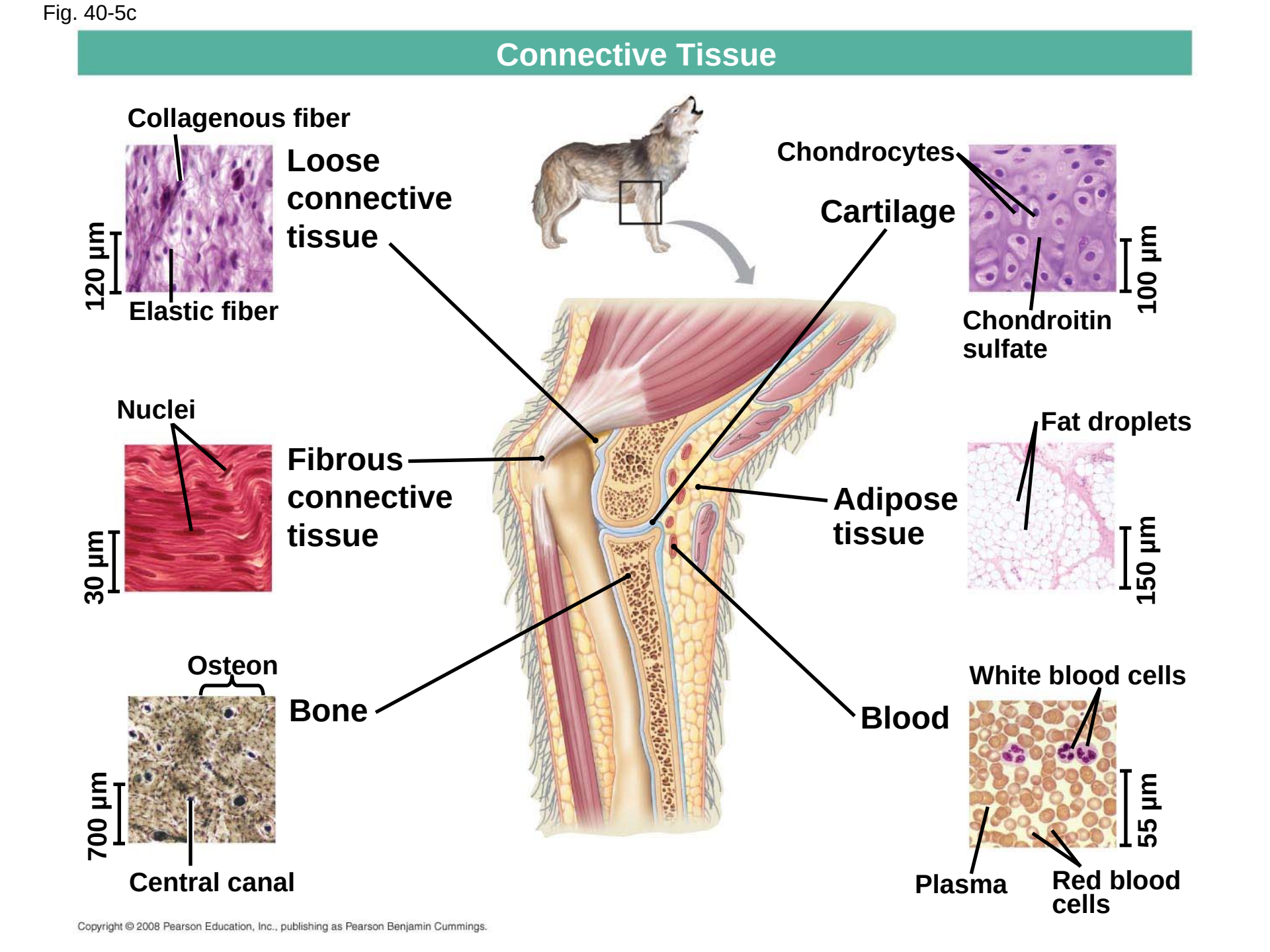
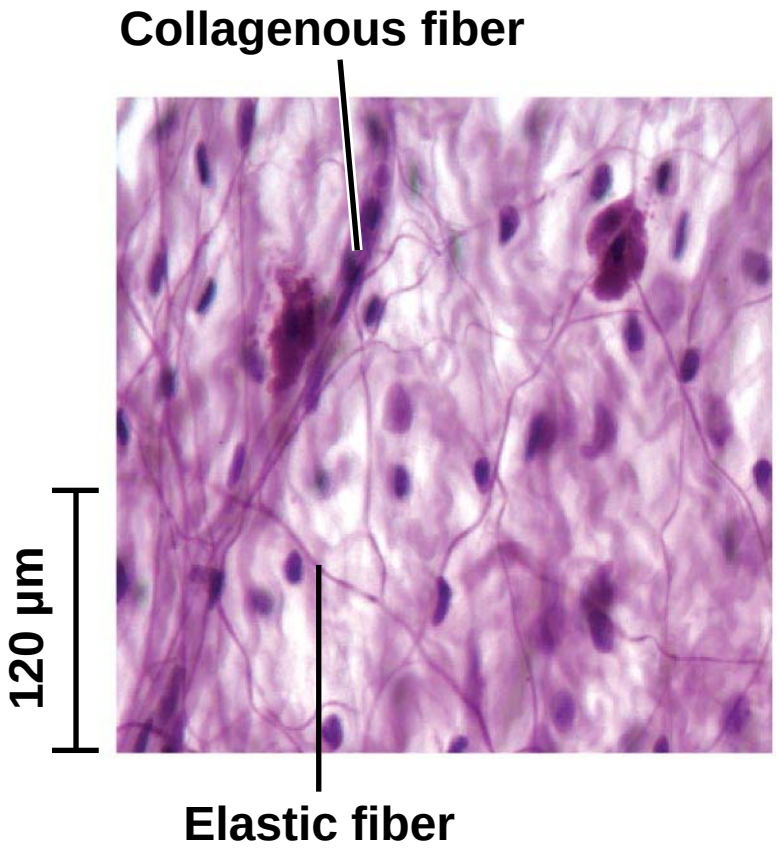
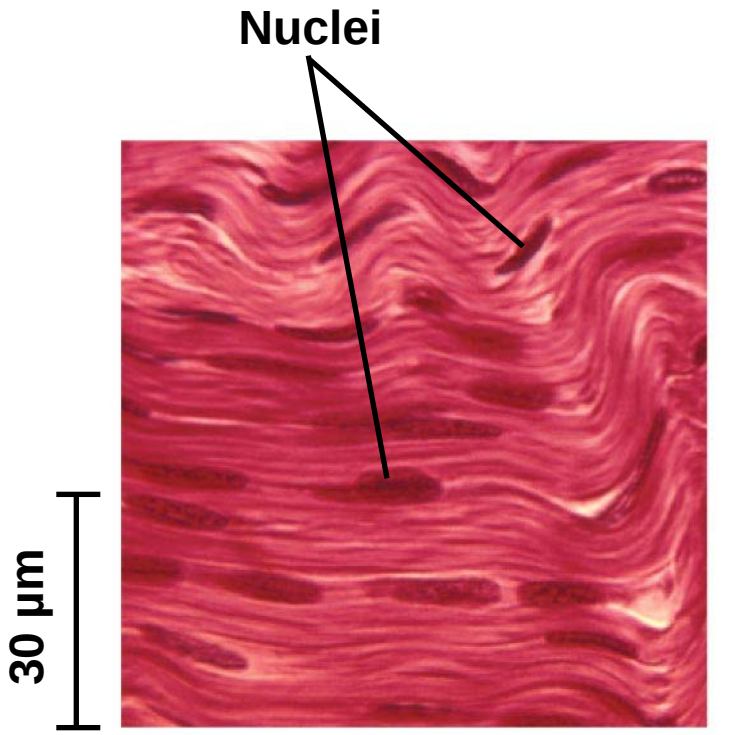


Fig. 40-5d



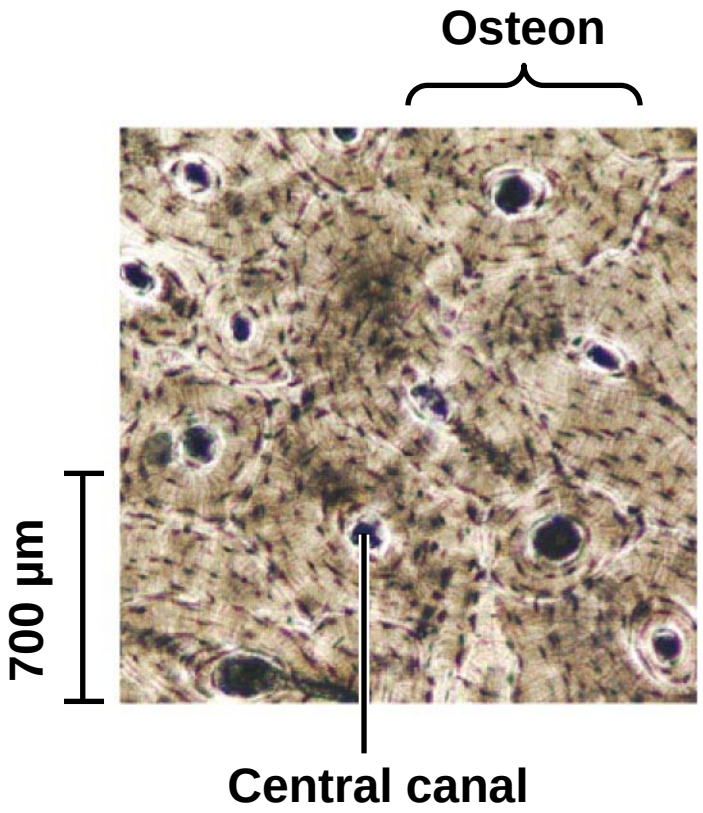
Loose connective tissue

Fig. 40-5e



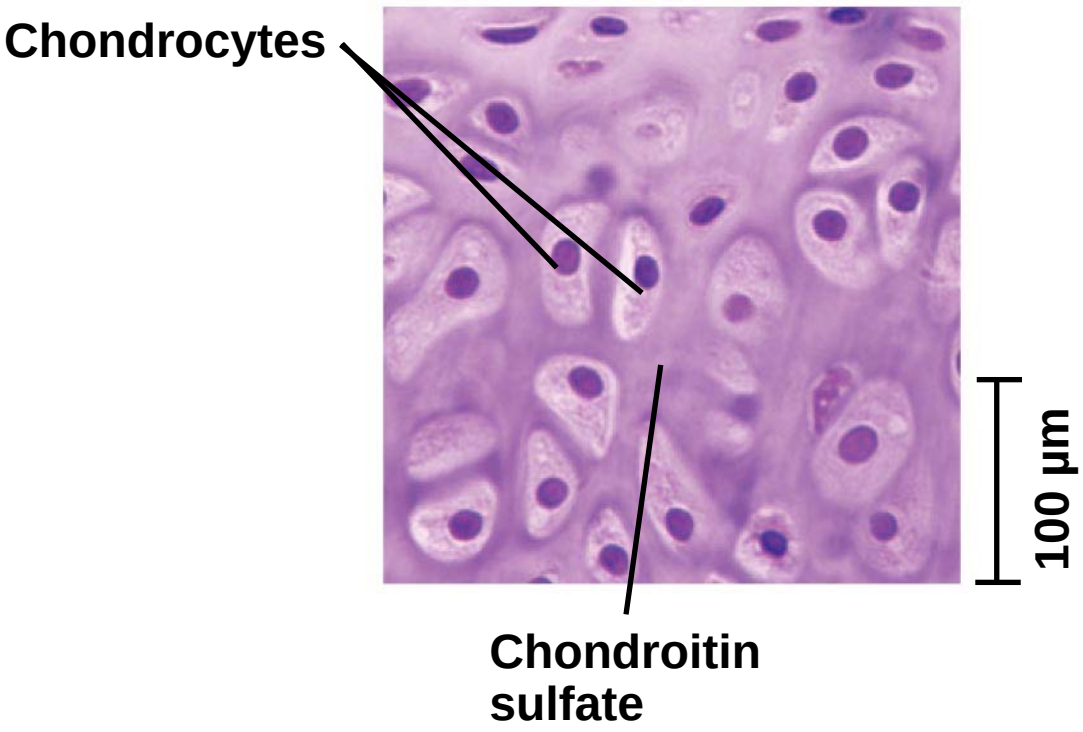
Fibrous connective tissue

Fig. 40-5f



Bone

Fig. 40-5g

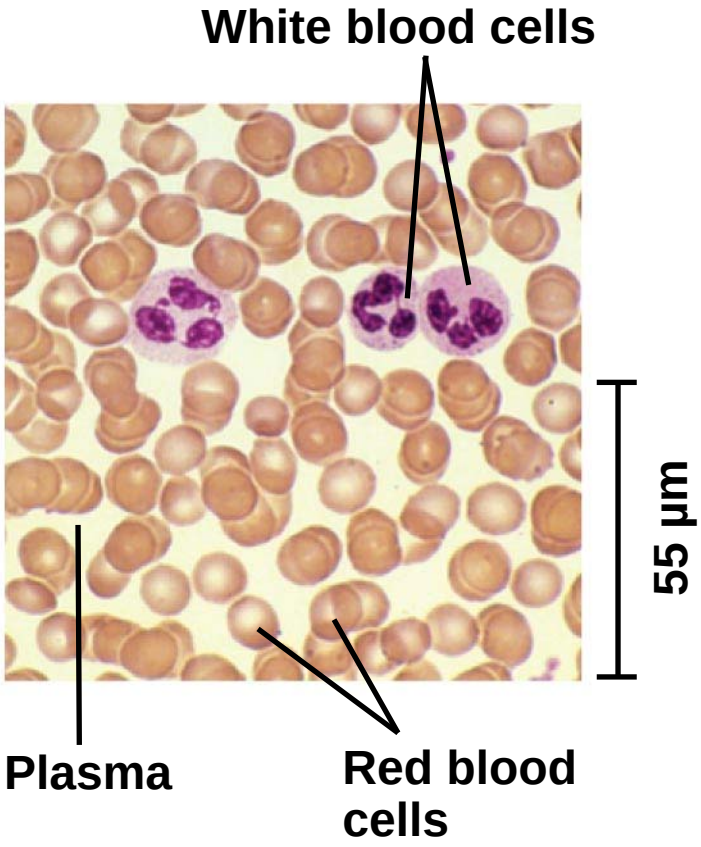


Cartilage

Fig. 40-5h

Adipose tissue

Fig. 40-5i



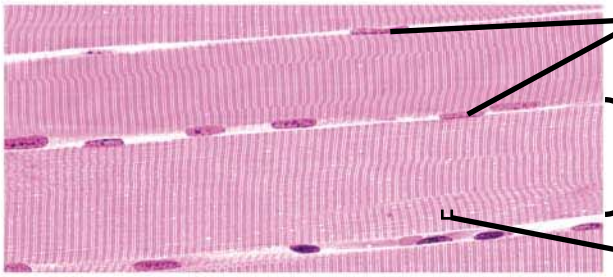
Blood

Muscle Tissue

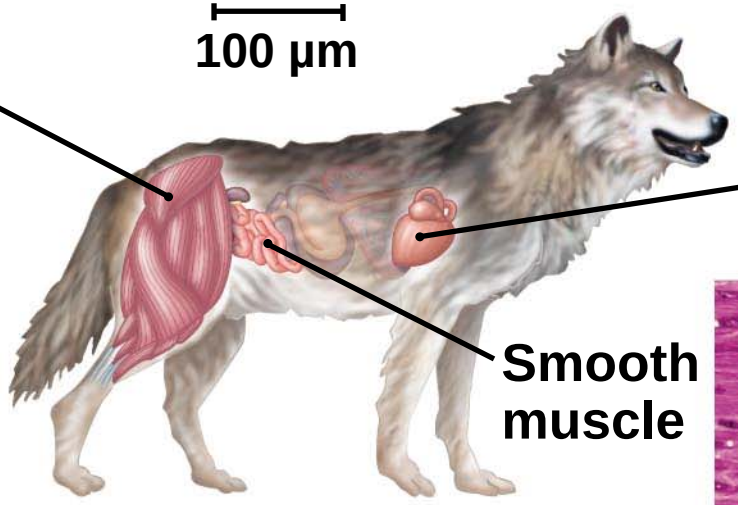
- **Muscle tissue** consists of long cells called muscle fibers, which contract in response to nerve signals
- It is divided in the vertebrate body into three types:
  - **Skeletal muscle**, or striated muscle, is responsible for voluntary movement
  - **Smooth muscle** is responsible for involuntary body activities
  - **Cardiac muscle** is responsible for contraction of the heart

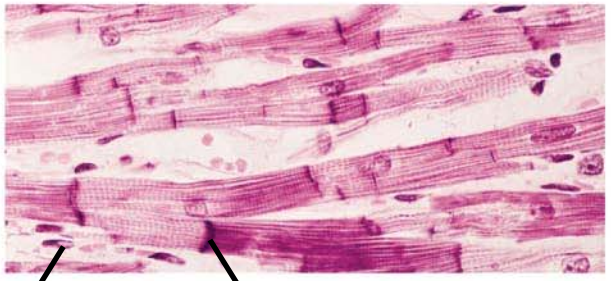
Fig. 40-5j

Muscle Tissue



Skeletal muscle





Cardiac muscle

Smooth muscle

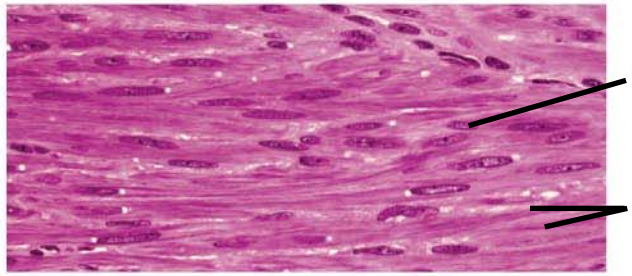
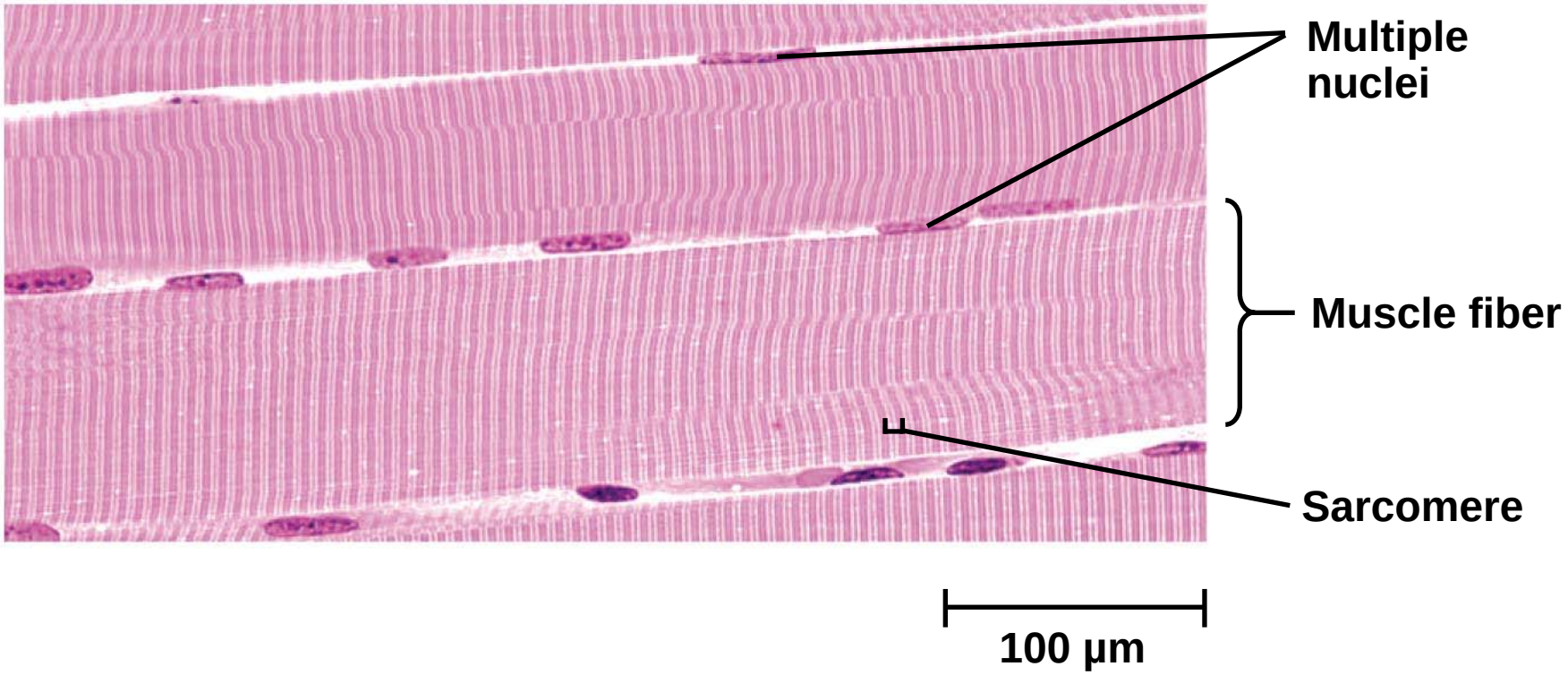
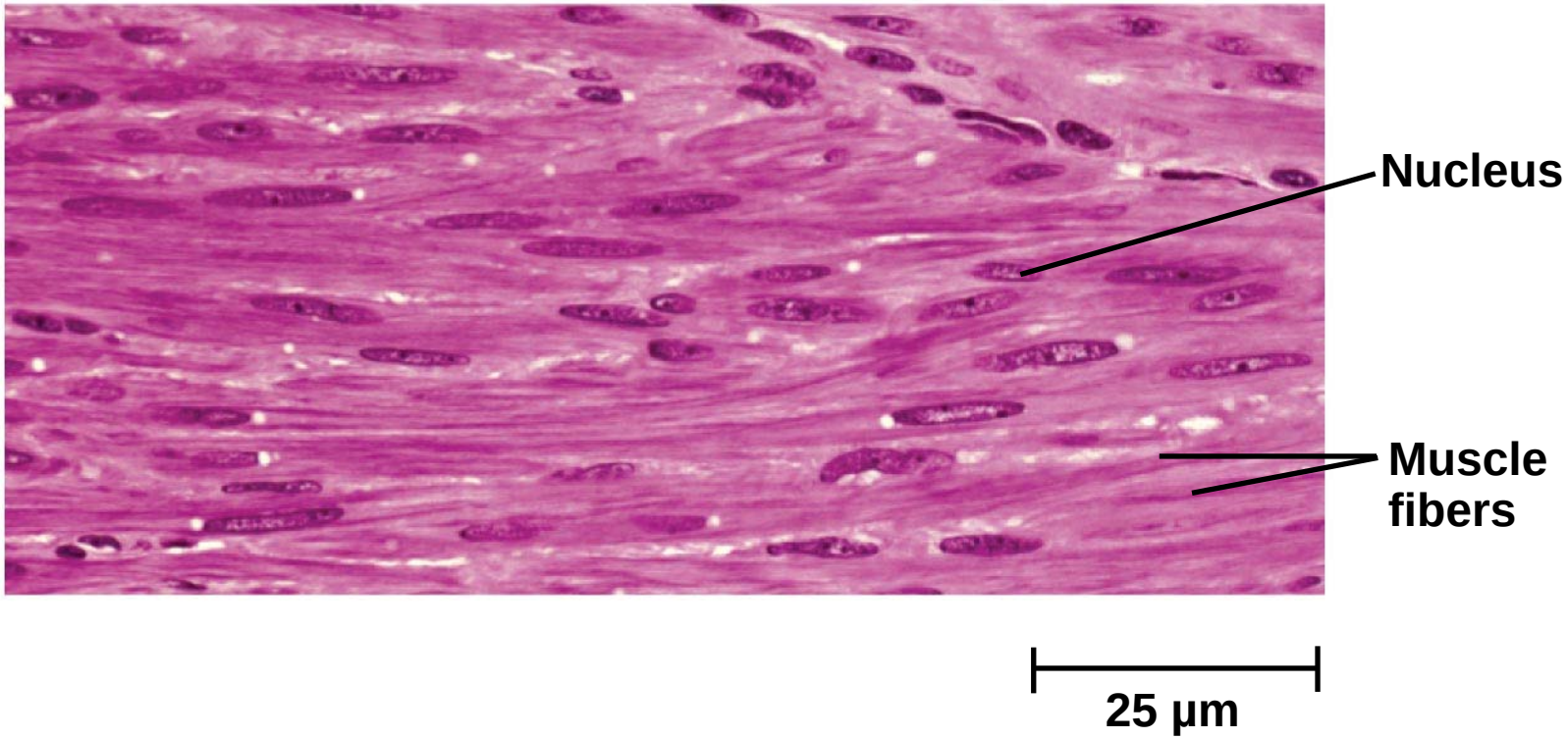


Fig. 40-5k



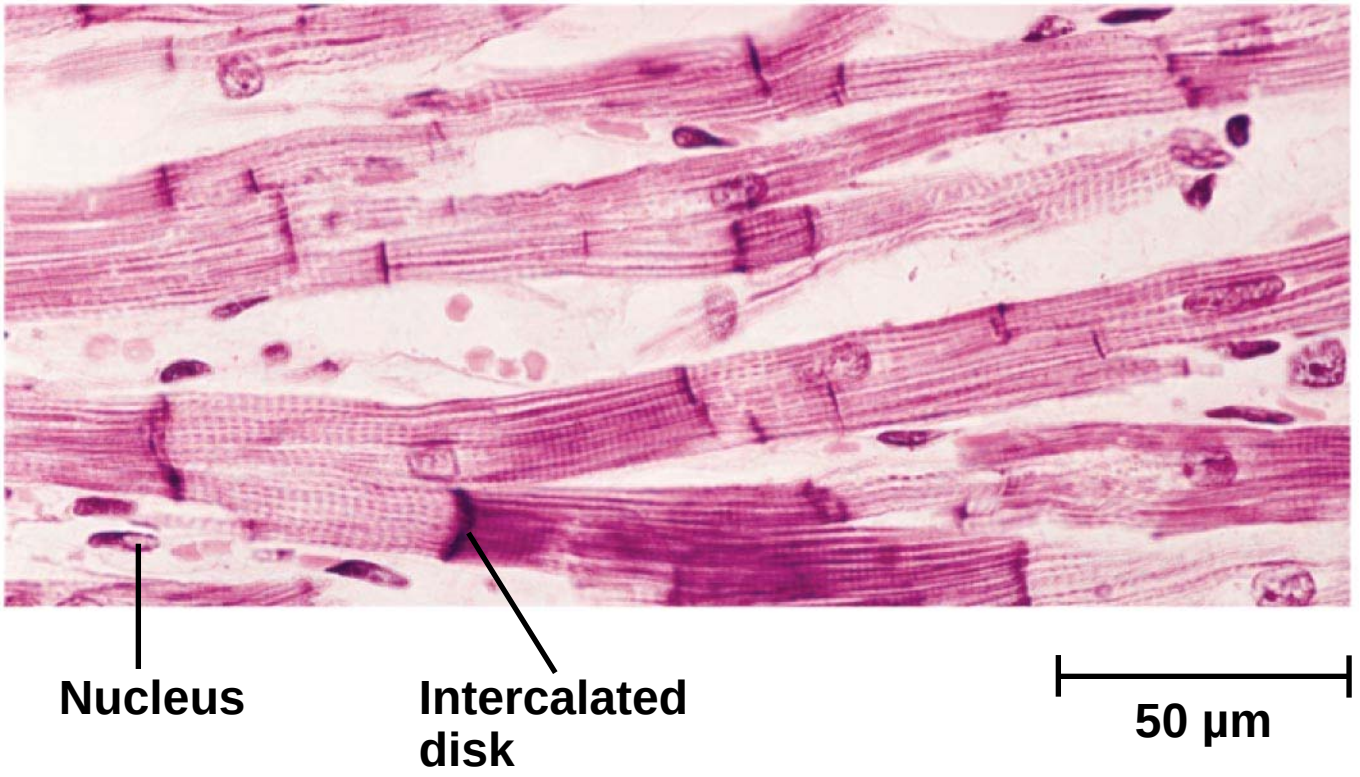
Skeletal muscle

Fig. 40-5l



Smooth muscle

Fig. 40-5m



Cardiac muscle

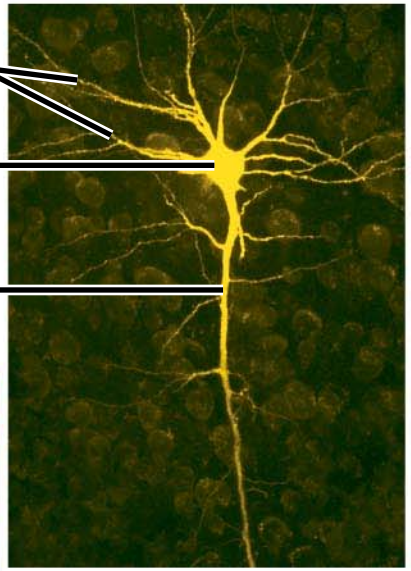
Nervous Tissue

- **Nervous tissue** senses stimuli and transmits signals throughout the animal
- Nervous tissue contains:
  - **Neurons**, or nerve cells, that transmit nerve impulses
  - **Glial cells**, or **glia**, that help nourish, insulate, and replenish neurons

Fig. 40-5n

Nervous Tissue

40 µm



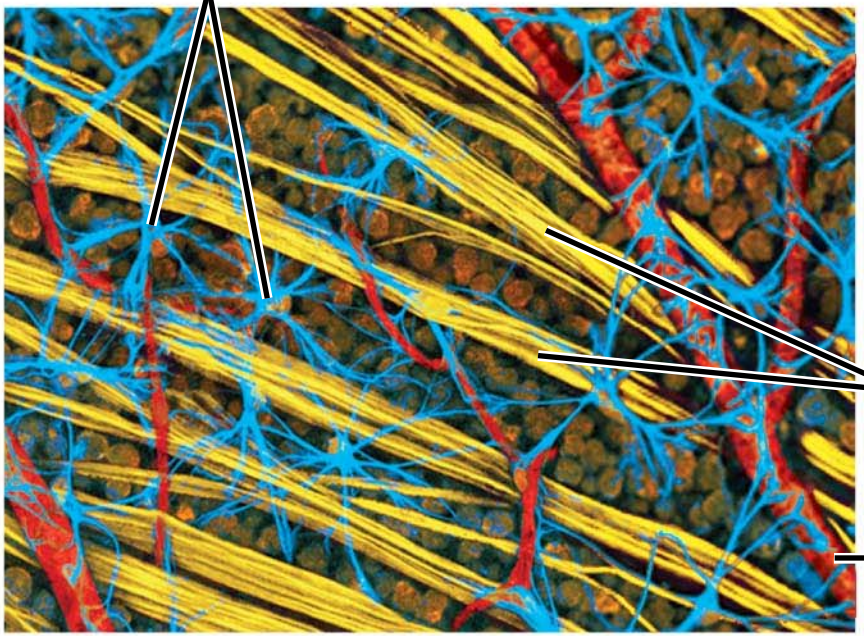
Dendrites

Cell body

Axon

Neuron

Glial cells

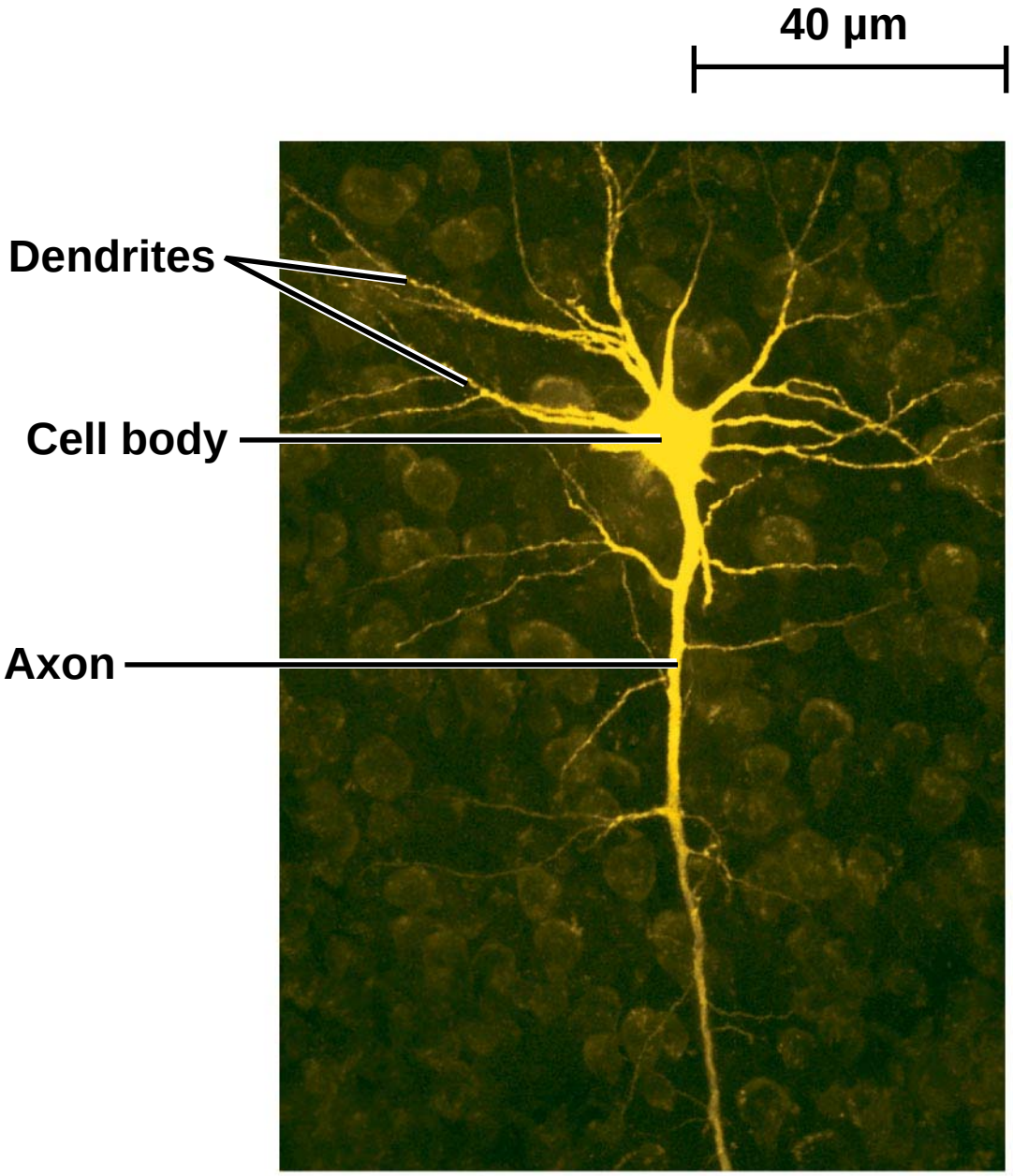


Axons

Blood vessel

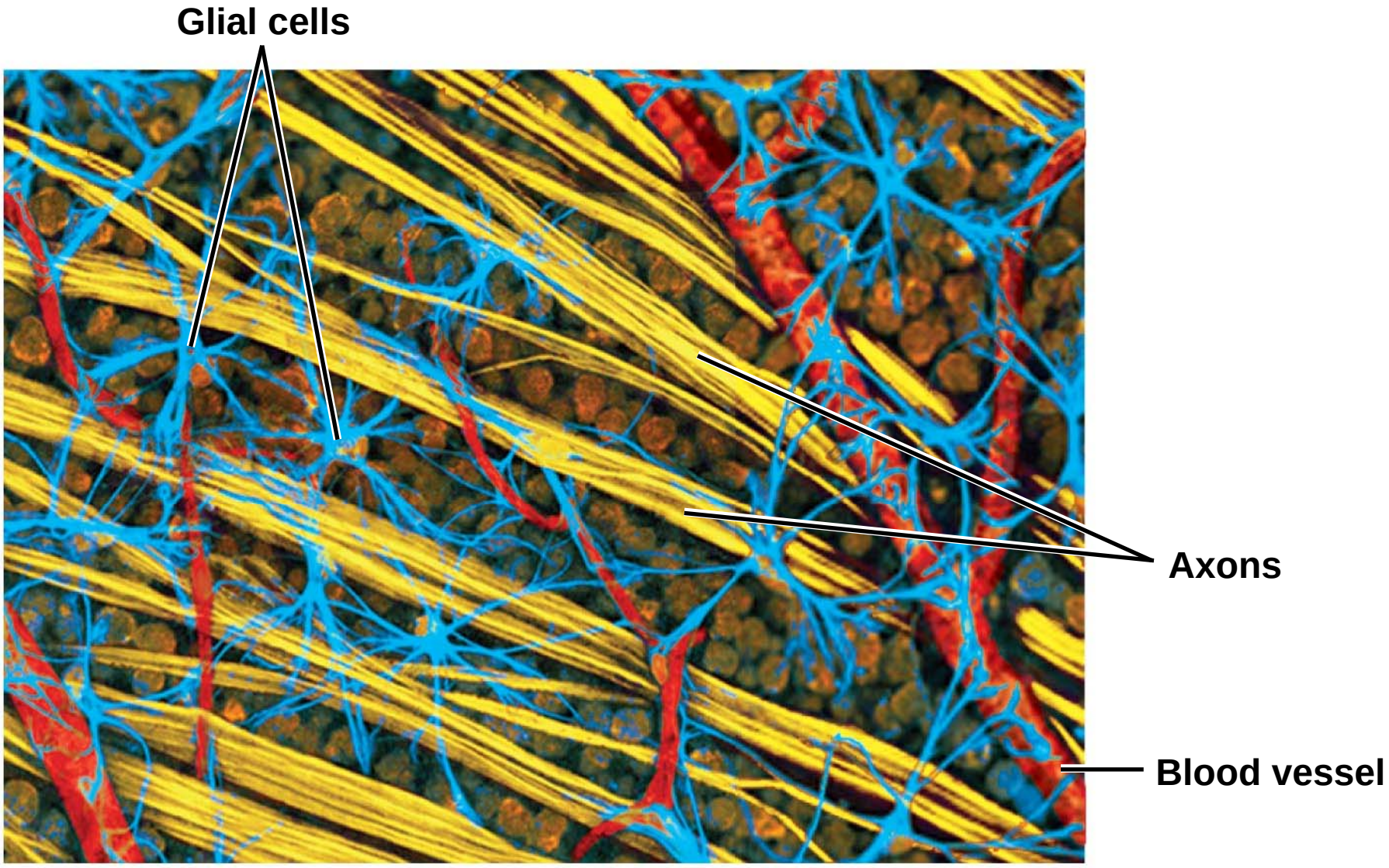
15 µm

Fig. 40-5o



Neuron

Fig. 40-5p



Glial cells and axons

Coordination and Control

- Control and coordination within a body depend on the endocrine system and the nervous system
- The endocrine system transmits chemical signals called **hormones** to receptive cells throughout the body via blood
- A hormone may affect one or more regions throughout the body
- Hormones are relatively slow acting, but can have long-lasting effects

Fig. 40-6

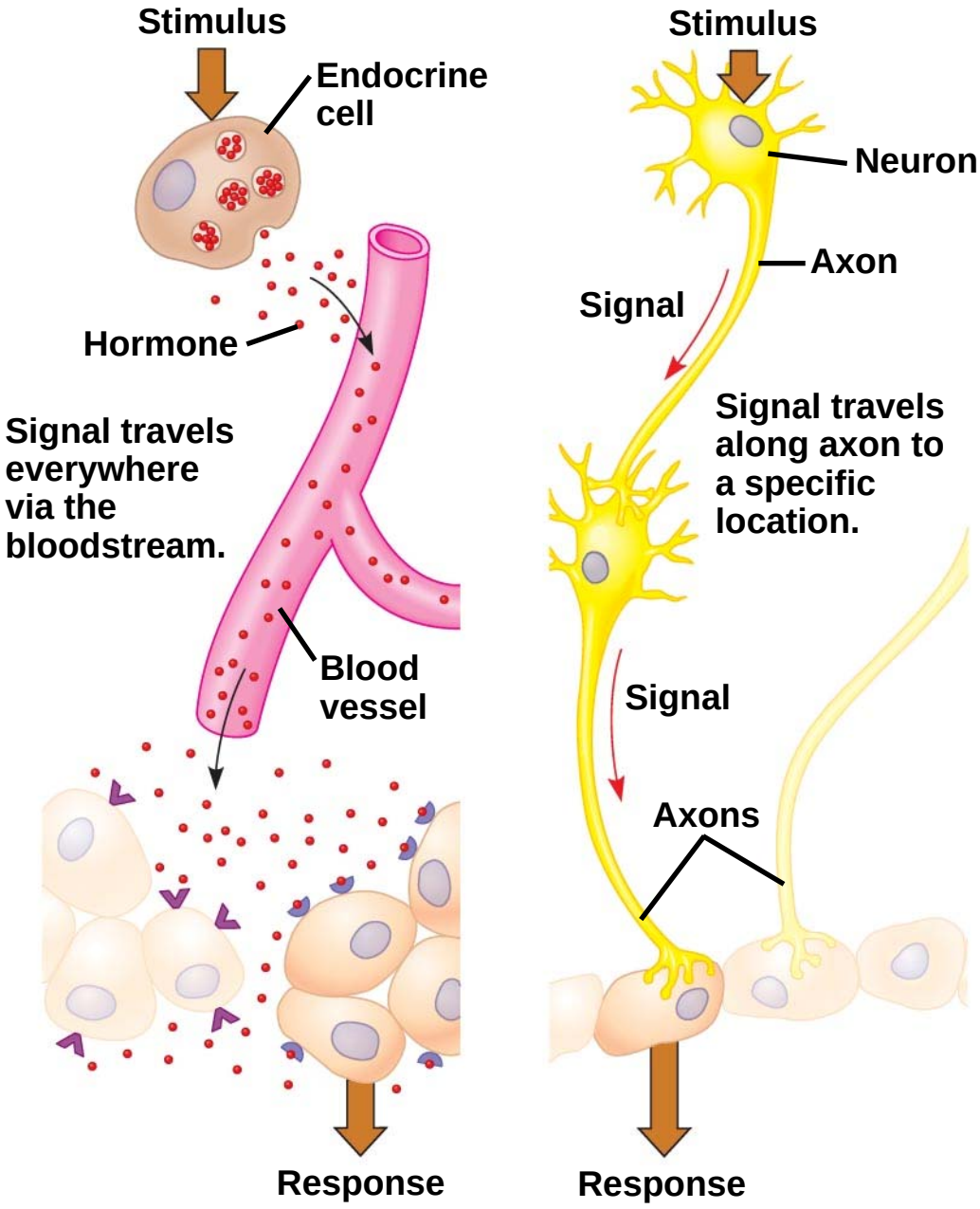
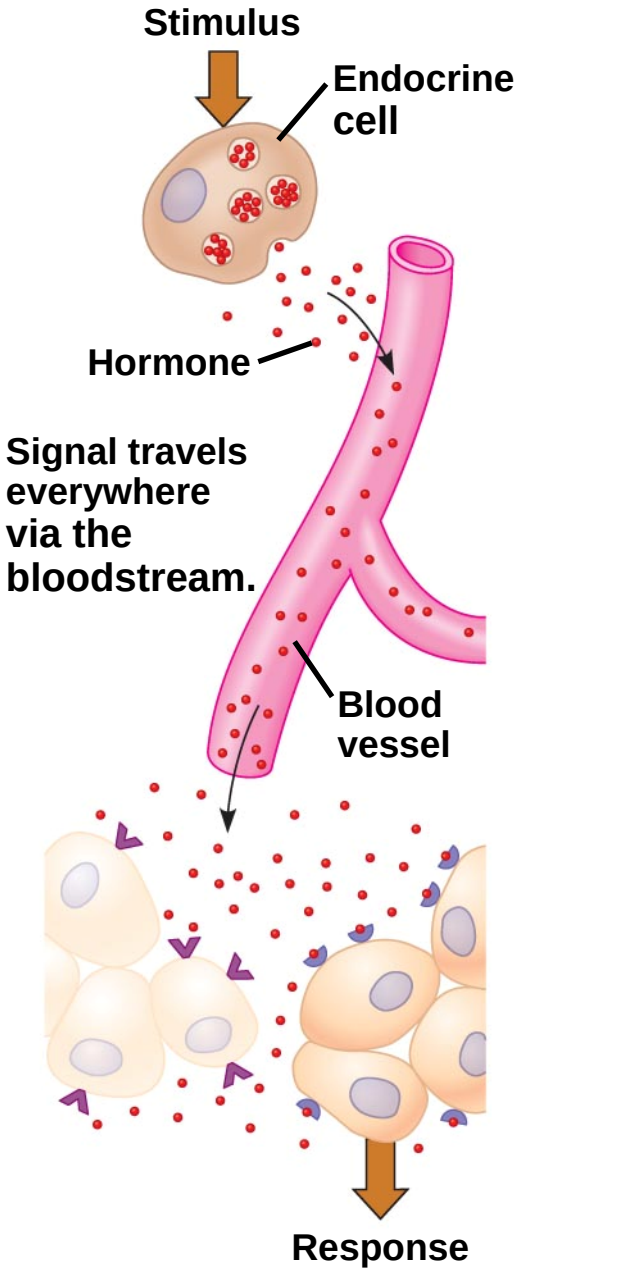


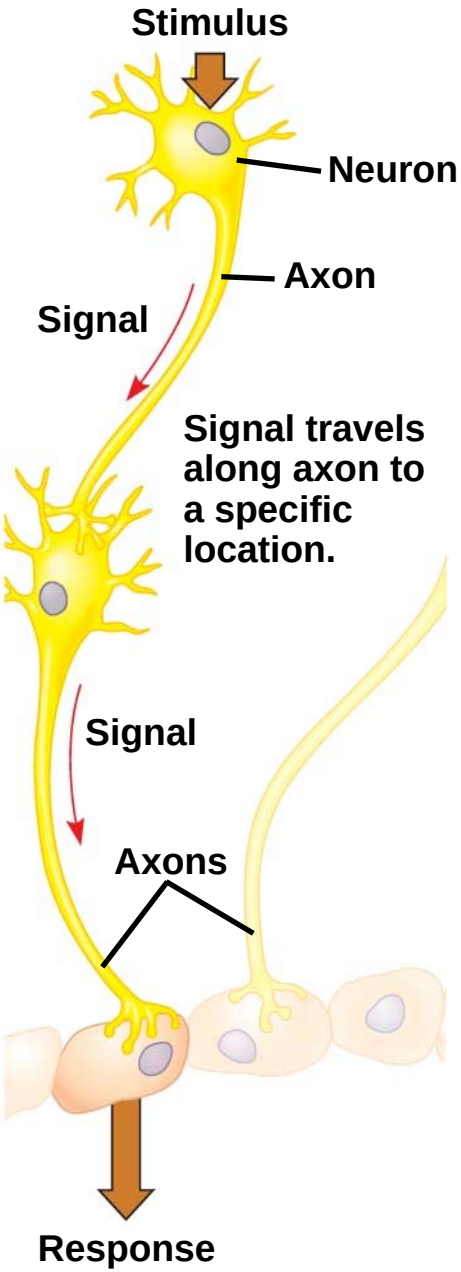
Fig. 40-6a



(a) Signaling by hormones

- The nervous system transmits information between specific locations
- The information conveyed depends on a signal's pathway, not the type of signal
- Nerve signal transmission is very fast
- Nerve impulses can be received by neurons, muscle cells, and endocrine cells

Fig. 40-6b



(b) Signaling by neurons

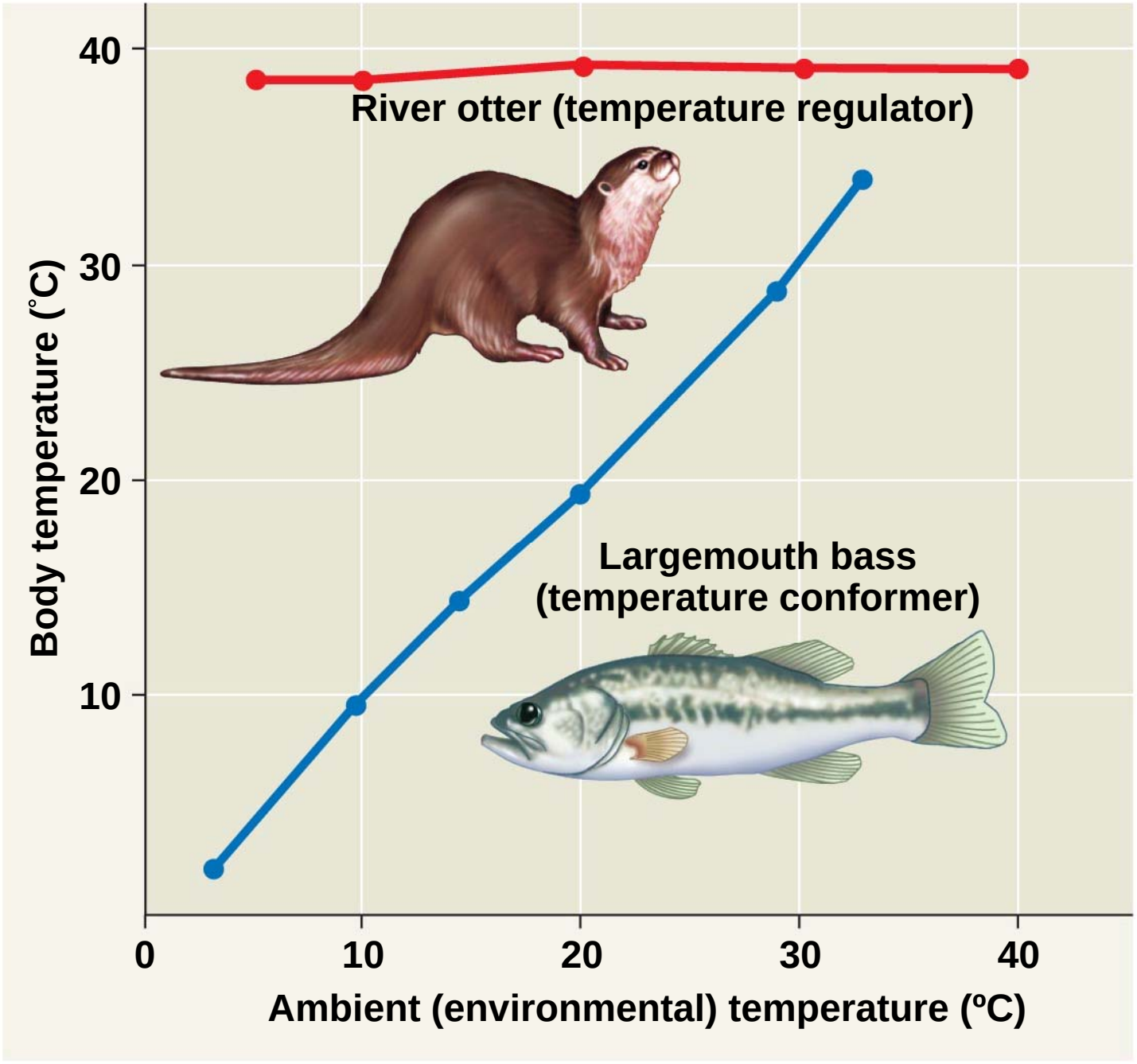
Concept 40.2: Feedback control loops maintain the internal environment in many animals

- Animals manage their internal environment by regulating or conforming to the external environment

Regulating and Conforming

- A **regulator** uses internal control mechanisms to moderate internal change in the face of external, environmental fluctuation
- A **conformer** allows its internal condition to vary with certain external changes

Fig. 40-7



Homeostasis

- Organisms use **homeostasis** to maintain a "steady state" or internal balance regardless of external environment
- In humans, body temperature, blood pH, and glucose concentration are each maintained at a constant level

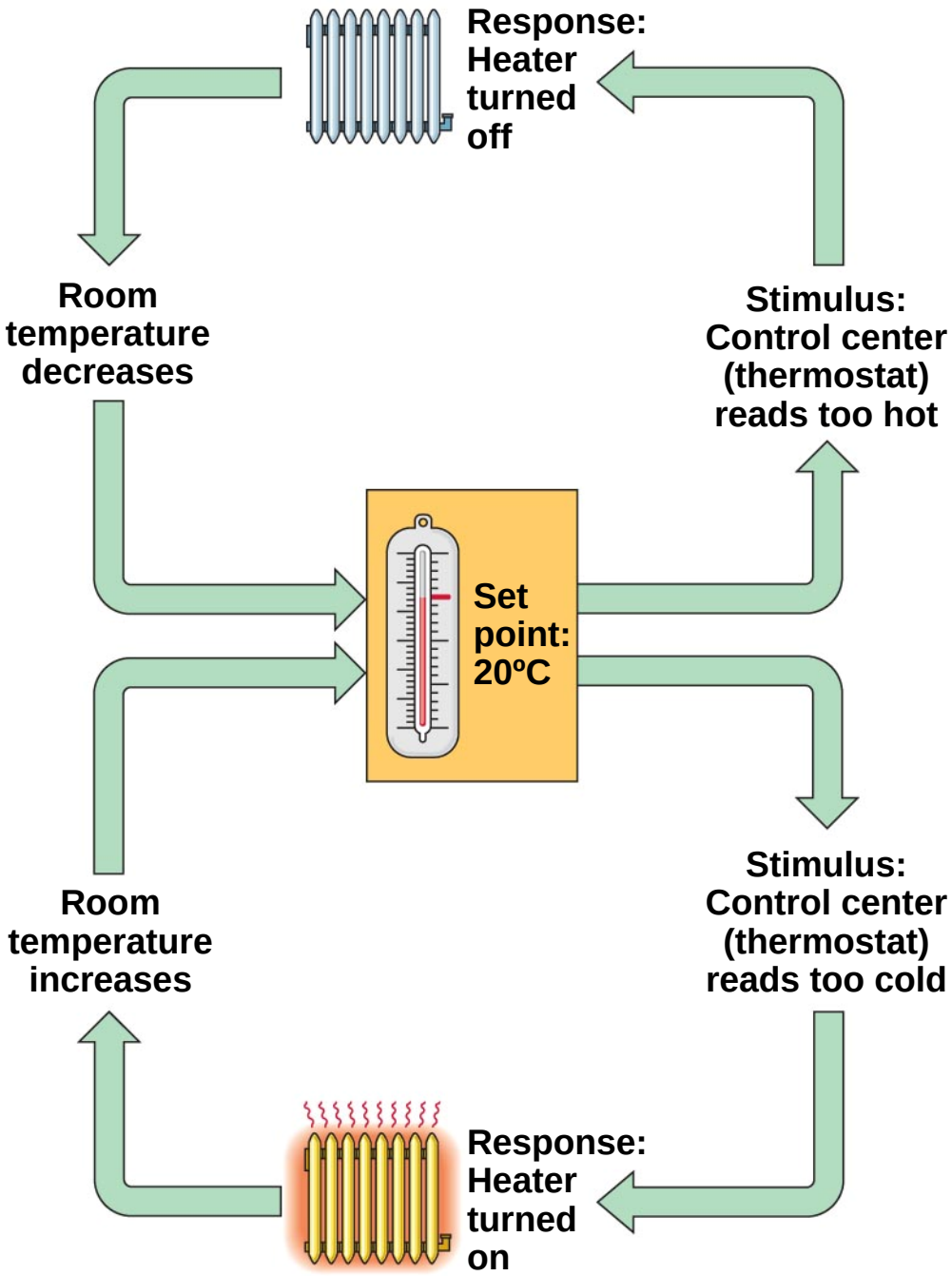
Mechanisms of Homeostasis

- Mechanisms of homeostasis moderate changes in the internal environment
- For a given variable, fluctuations above or below a **set point** serve as a **stimulus**; these are detected by a **sensor** and trigger a **response**
- The response returns the variable to the set point

PLAY Animation: Negative Feedback

PLAY Animation: Positive Feedback

Fig. 40-8



Feedback Loops in Homeostasis

- The dynamic equilibrium of homeostasis is maintained by **negative feedback,** which helps to return a variable to either a **normal range** or a set point
- Most homeostatic control systems function by negative feedback, where buildup of the end product shuts the system off
- **Positive feedback** loops occur in animals, but do not usually contribute to homeostasis

Alterations in Homeostasis

- Set points and normal ranges can change with age or show cyclic variation
- Homeostasis can adjust to changes in external environment, a process called **acclimatization**

Concept 40.3: Homeostatic processes for thermoregulation involve form, function, and behavior

- **Thermoregulation** is the process by which animals maintain an internal temperature within a tolerable range

Endothermy and Ectothermy

- **Endothermic** animals generate heat by metabolism; birds and mammals are endotherms
- **Ectothermic** animals gain heat from external sources; ectotherms include most invertebrates, fishes, amphibians, and non-avian reptiles

- In general, ectotherms tolerate greater variation in internal temperature, while endotherms are active at a greater range of external temperatures
- Endothermy is more energetically expensive than ectothermy

Fig. 40-9

(a) A walrus, an endotherm

(b) A lizard, an ectotherm

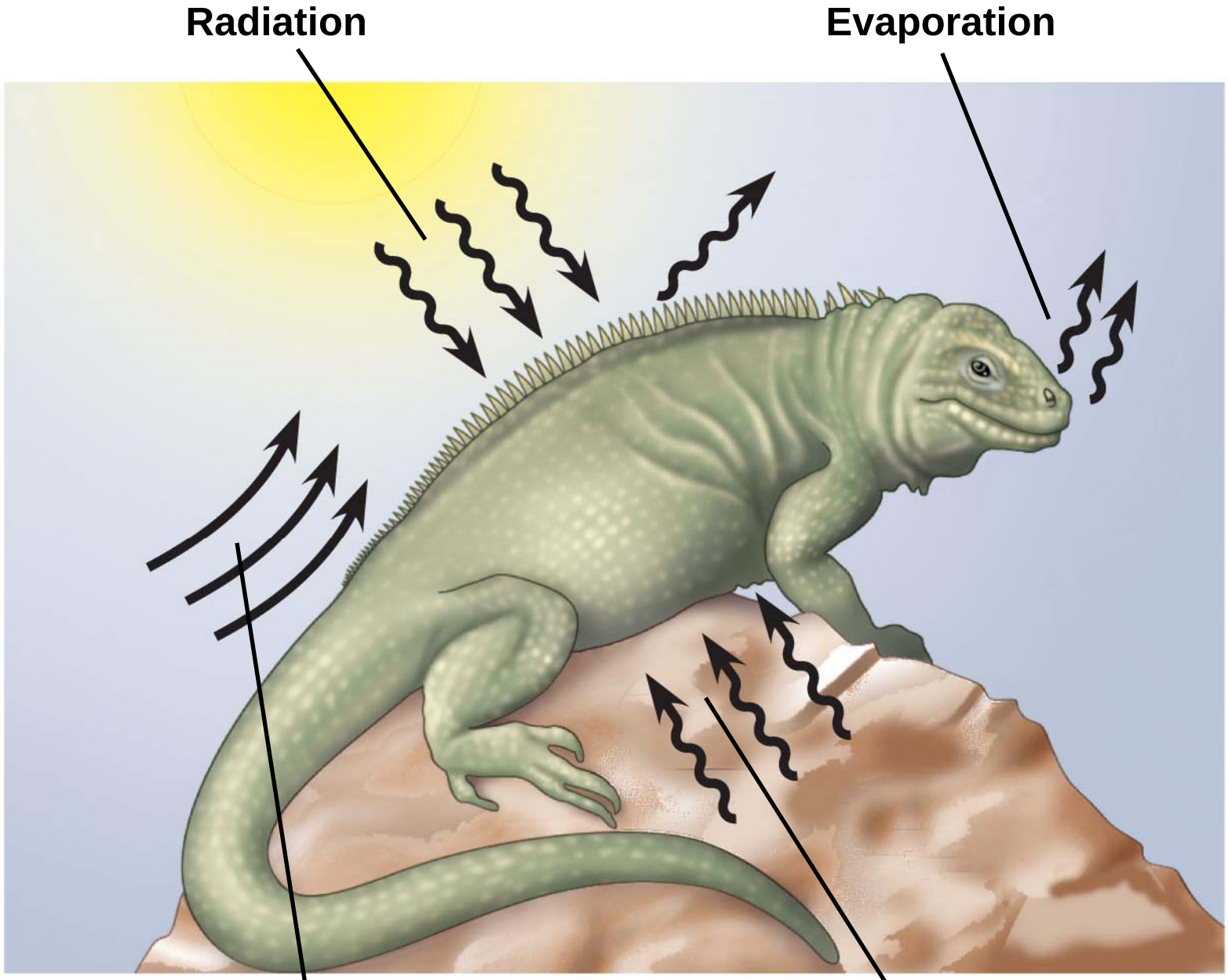
Variation in Body Temperature

- The body temperature of a *poikilotherm* varies with its environment, while that of a *homeotherm* is relatively constant

Balancing Heat Loss and Gain

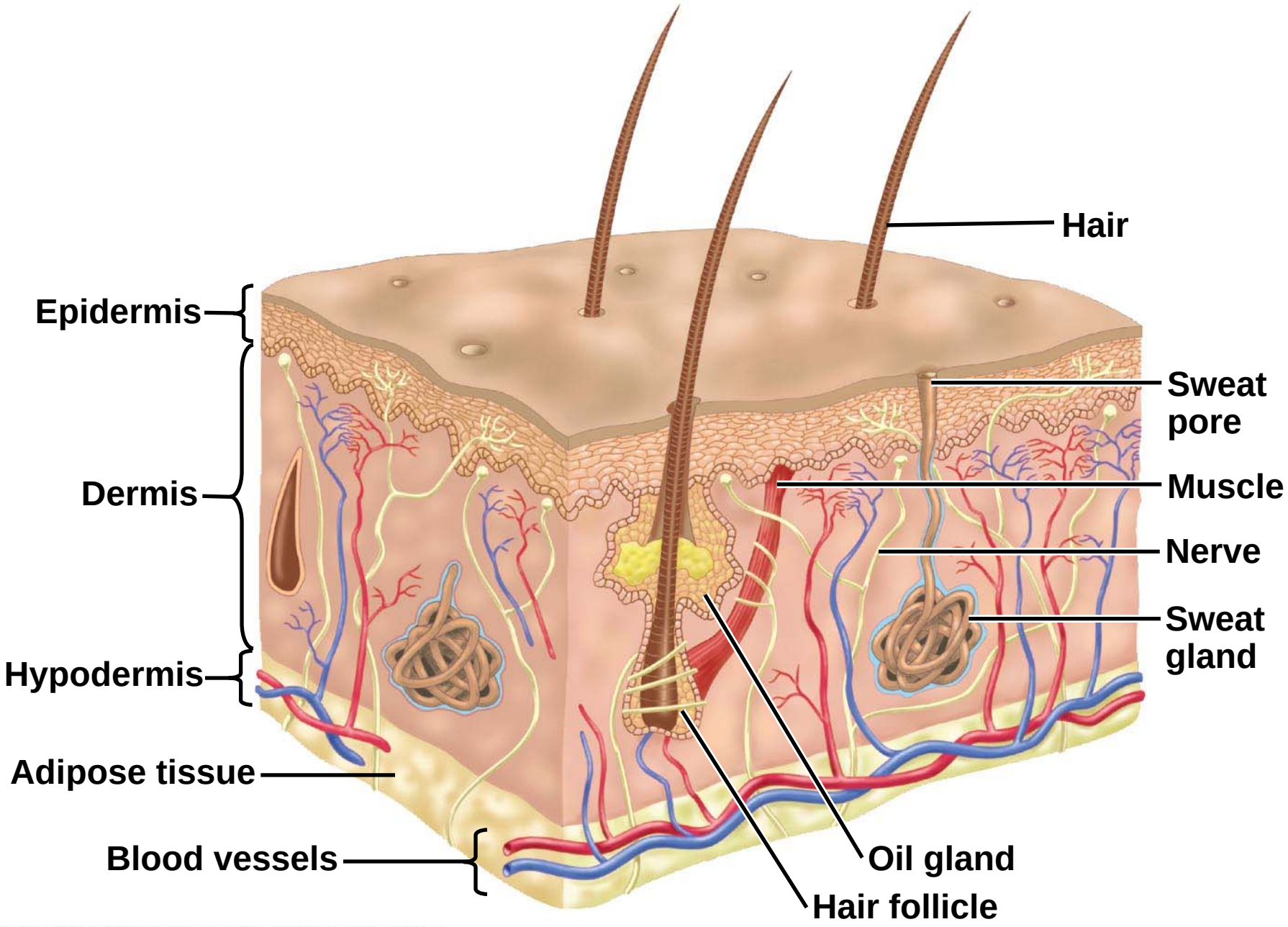
- Organisms exchange heat by four physical processes: conduction, convection, radiation, and evaporation

Fig. 40-10



- Heat regulation in mammals often involves the **integumentary system**: skin, hair, and nails

Fig. 40-11



- Five general adaptations help animals thermoregulate:
  - Insulation
  - Circulatory adaptations
  - Cooling by evaporative heat loss
  - Behavioral responses
  - Adjusting metabolic heat production

Insulation

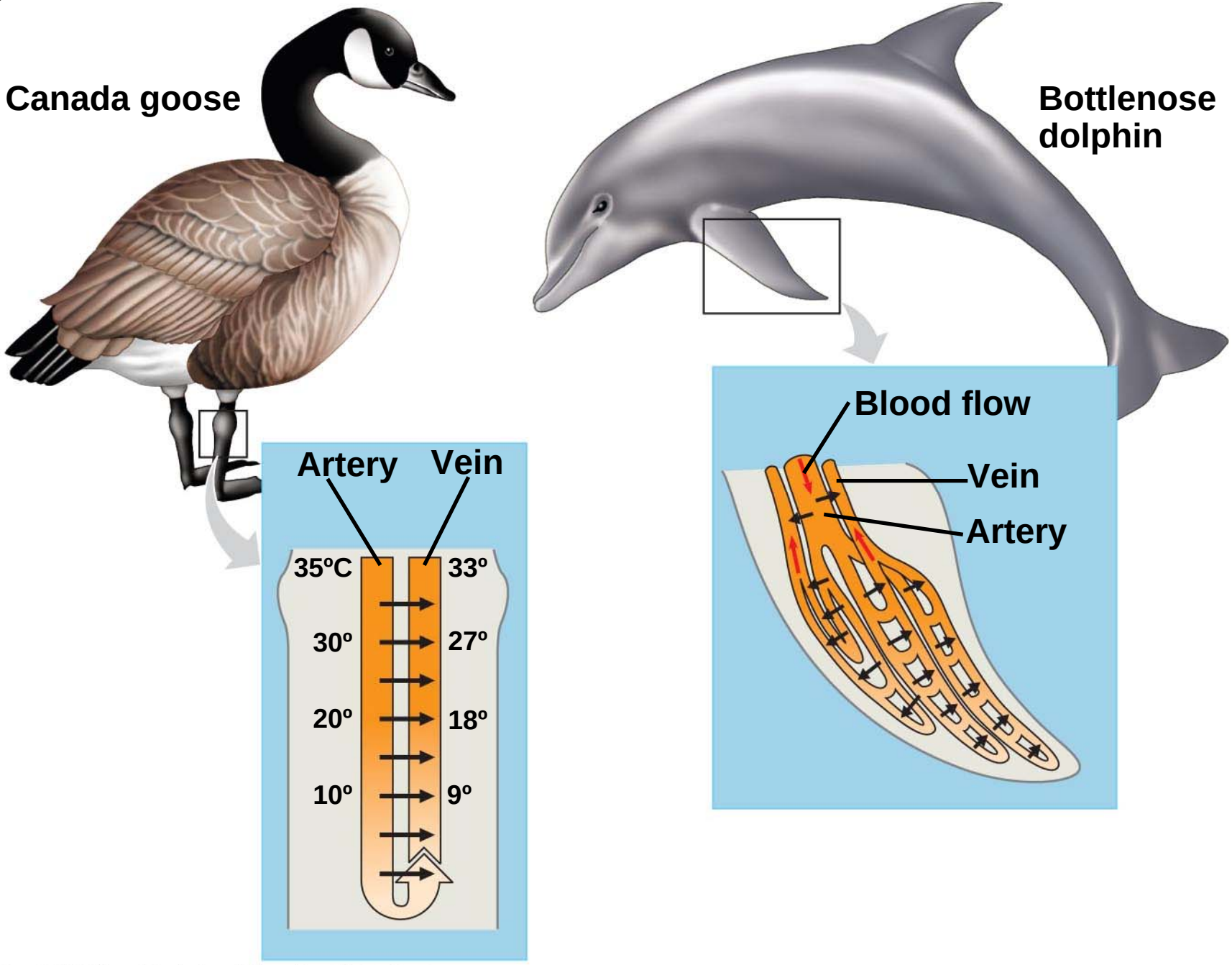
- Insulation is a major thermoregulatory adaptation in mammals and birds
- Skin, feathers, fur, and blubber reduce heat flow between an animal and its environment

Circulatory Adaptations

- Regulation of blood flow near the body surface significantly affects thermoregulation
- Many endotherms and some ectotherms can alter the amount of blood flowing between the body core and the skin
- In vasodilation, blood flow in the skin increases, facilitating heat loss
- In vasoconstriction, blood flow in the skin decreases, lowering heat loss

- The arrangement of blood vessels in many marine mammals and birds allows for **countercurrent exchange**
- Countercurrent heat exchangers transfer heat between fluids flowing in opposite directions
- Countercurrent heat exchangers are an important mechanism for reducing heat loss

Fig. 40-12



- Some bony fishes and sharks also use countercurrent heat exchanges
- Many endothermic insects have countercurrent heat exchangers that help maintain a high temperature in the thorax

Cooling by Evaporative Heat Loss

- Many types of animals lose heat through evaporation of water in sweat
- Panting increases the cooling effect in birds and many mammals
- Sweating or bathing moistens the skin, helping to cool an animal down

Behavioral Responses

- Both endotherms and ectotherms use behavioral responses to control body temperature
- Some terrestrial invertebrates have postures that minimize or maximize absorption of solar heat

Fig. 40-13

Adjusting Metabolic Heat Production

- Some animals can regulate body temperature by adjusting their rate of metabolic heat production
- Heat production is increased by muscle activity such as moving or shivering
- Some ectotherms can also shiver to increase body temperature

Fig. 40-14

RESULTS

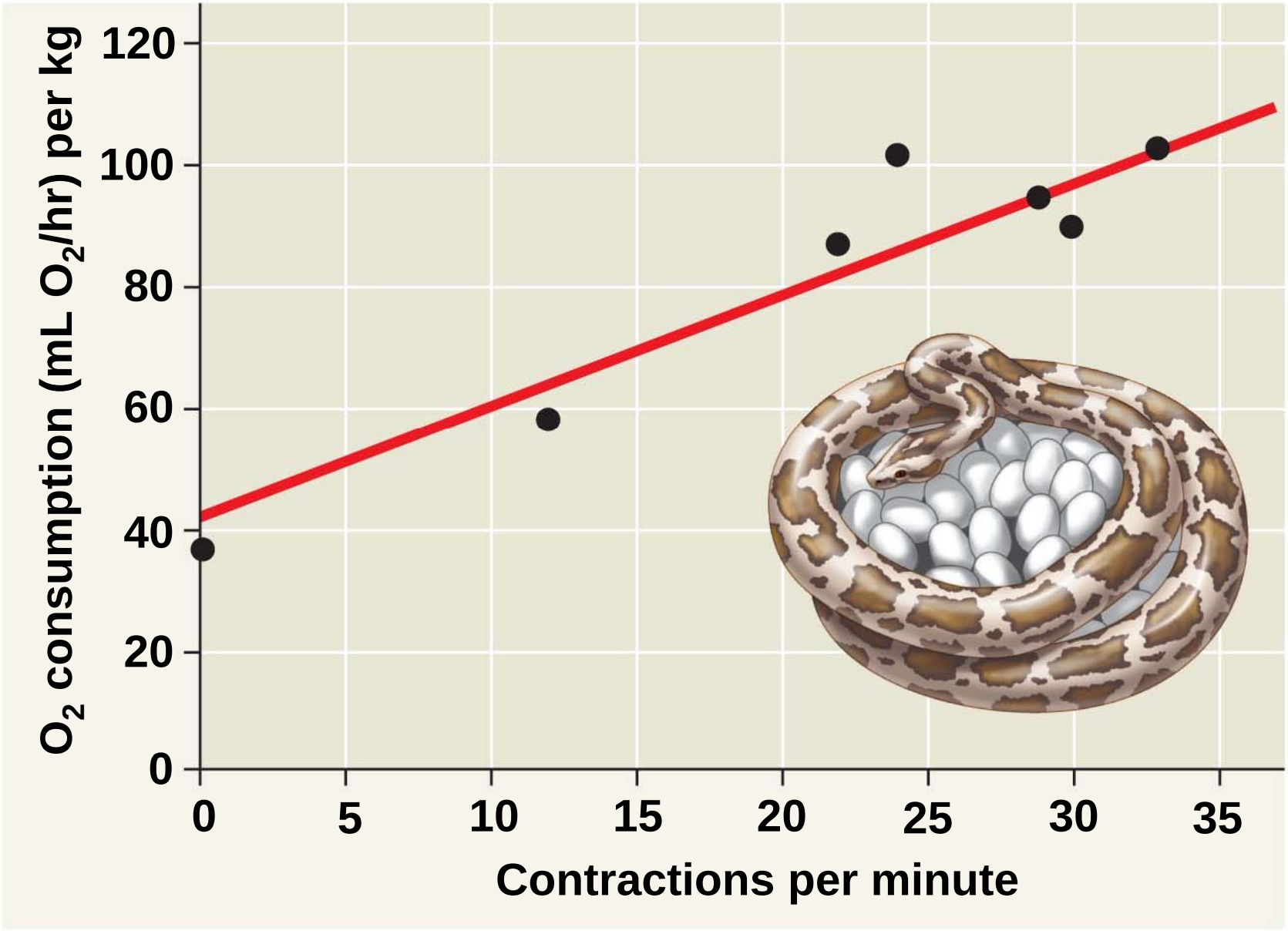
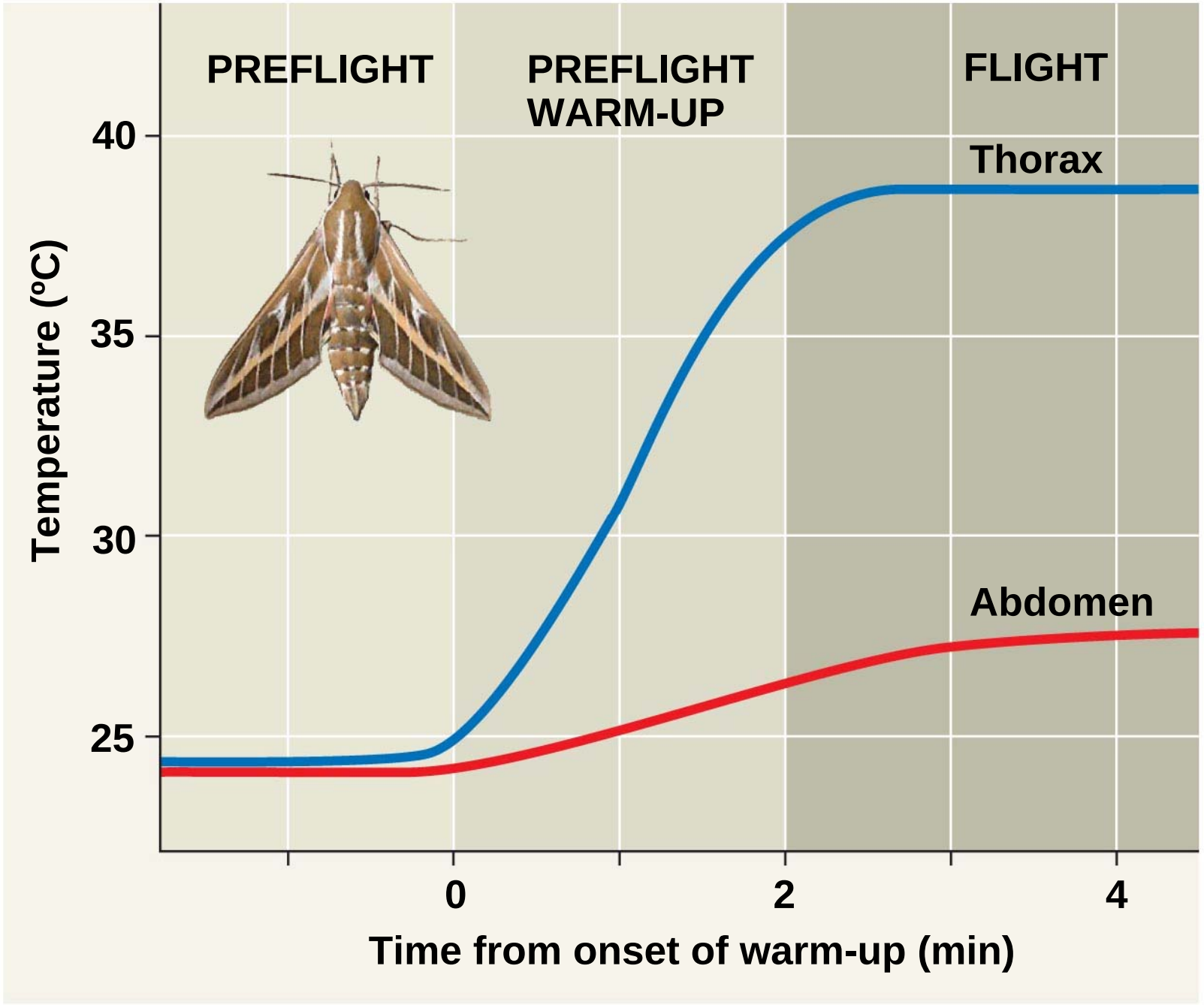


Fig. 40-15



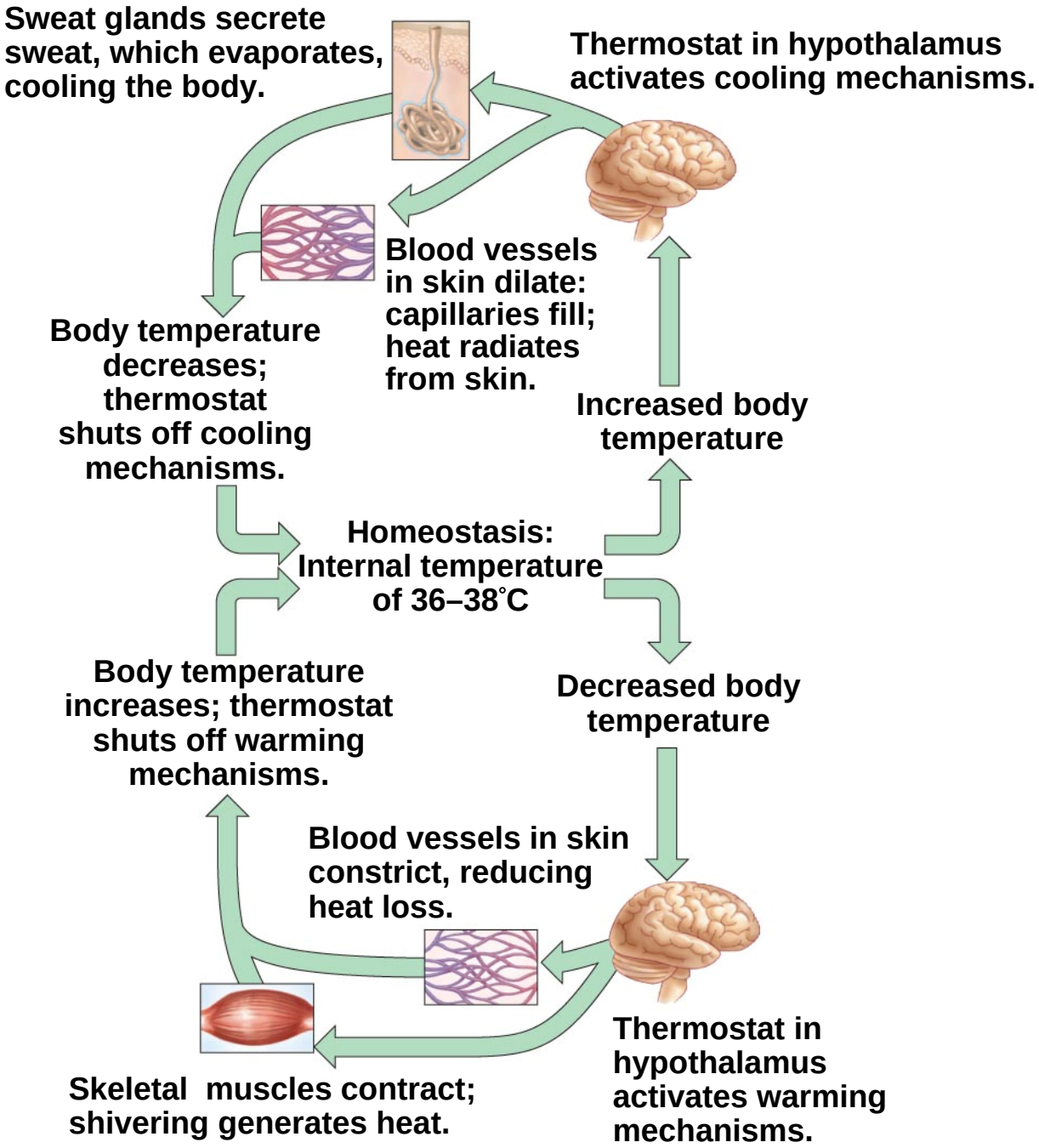
Acclimatization in Thermoregulation

- Birds and mammals can vary their insulation to acclimatize to seasonal temperature changes
- When temperatures are subzero, some ectotherms produce “antifreeze” compounds to prevent ice formation in their cells

Physiological Thermostats and Fever

- Thermoregulation is controlled by a region of the brain called the **hypothalamus**
- The hypothalamus triggers heat loss or heat generating mechanisms
- Fever is the result of a change to the set point for a biological thermostat

Fig. 40-16



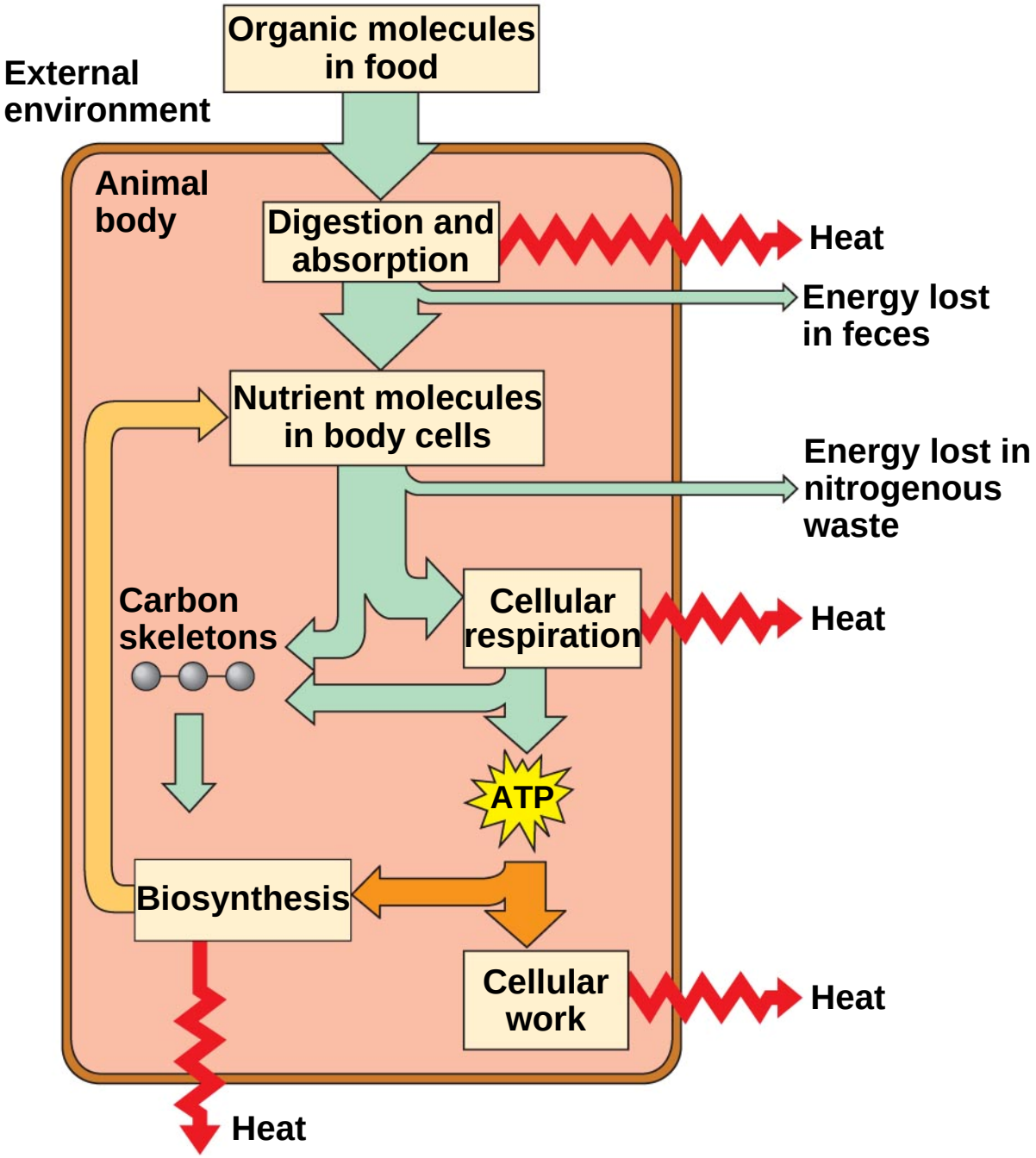
Concept 40.4: Energy requirements are related to animal size, activity, and environment

- **Bioenergetics** is the overall flow and transformation of energy in an animal
- It determines how much food an animal needs and relates to an animal's size, activity, and environment

Energy Allocation and Use

- Animals harvest chemical energy from food
- Energy-containing molecules from food are usually used to make ATP, which powers cellular work
- After the needs of staying alive are met, remaining food molecules can be used in biosynthesis
- Biosynthesis includes body growth and repair, synthesis of storage material such as fat, and production of gametes

Fig. 40-17



Quantifying Energy Use

- **Metabolic rate** is the amount of energy an animal uses in a unit of time
- One way to measure it is to determine the amount of oxygen consumed or carbon dioxide produced

Fig. 40-18

Minimum Metabolic Rate and Thermoregulation

- **Basal metabolic rate (BMR)** is the metabolic rate of an endotherm at rest at a "comfortable" temperature
- **Standard metabolic rate (SMR)** is the metabolic rate of an ectotherm at rest at a specific temperature
- Both rates assume a nongrowing, fasting, and nonstressed animal
- Ectotherms have much lower metabolic rates than endotherms of a comparable size

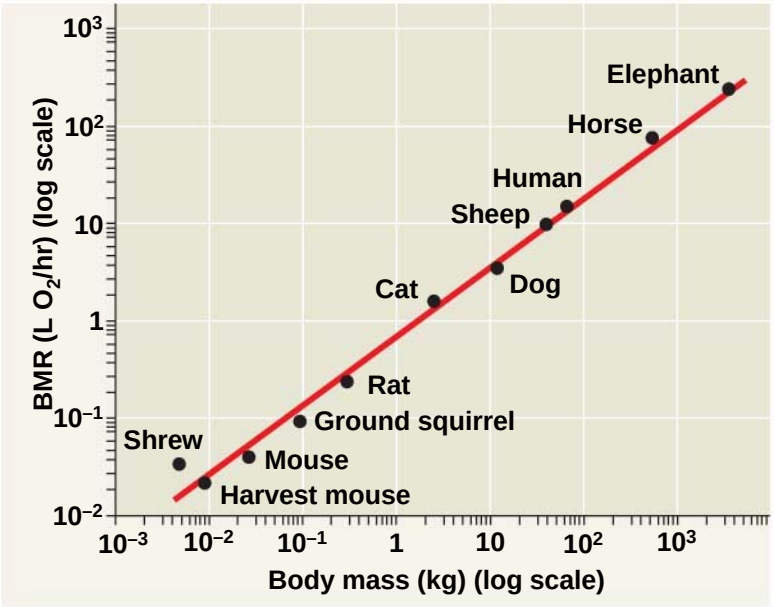
Influences on Metabolic Rate

- Metabolic rates are affected by many factors besides whether an animal is an endotherm or ectotherm
- Two of these factors are size and activity

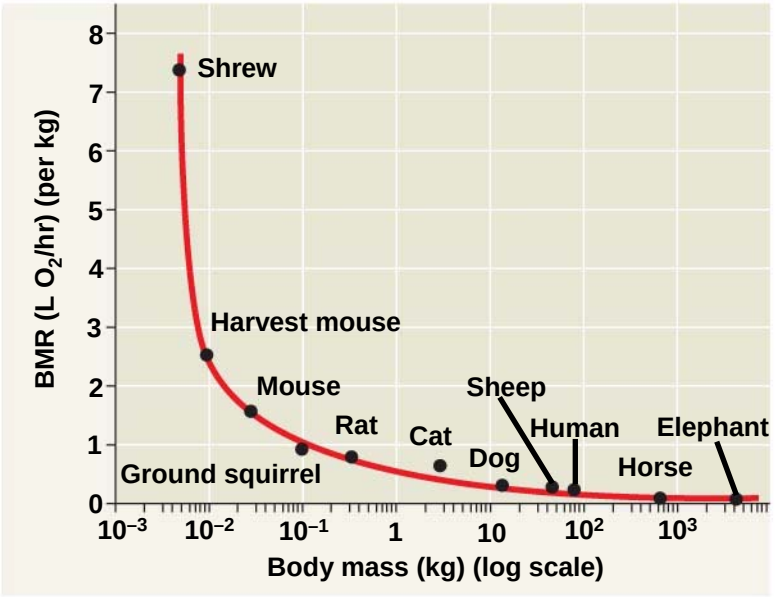
Size and Metabolic Rate

- Metabolic rate per gram is inversely related to body size among similar animals
- Researchers continue to search for the causes of this relationship
- The higher metabolic rate of smaller animals leads to a higher oxygen delivery rate, breathing rate, heart rate, and greater (relative) blood volume, compared with a larger animal

Fig. 40-19

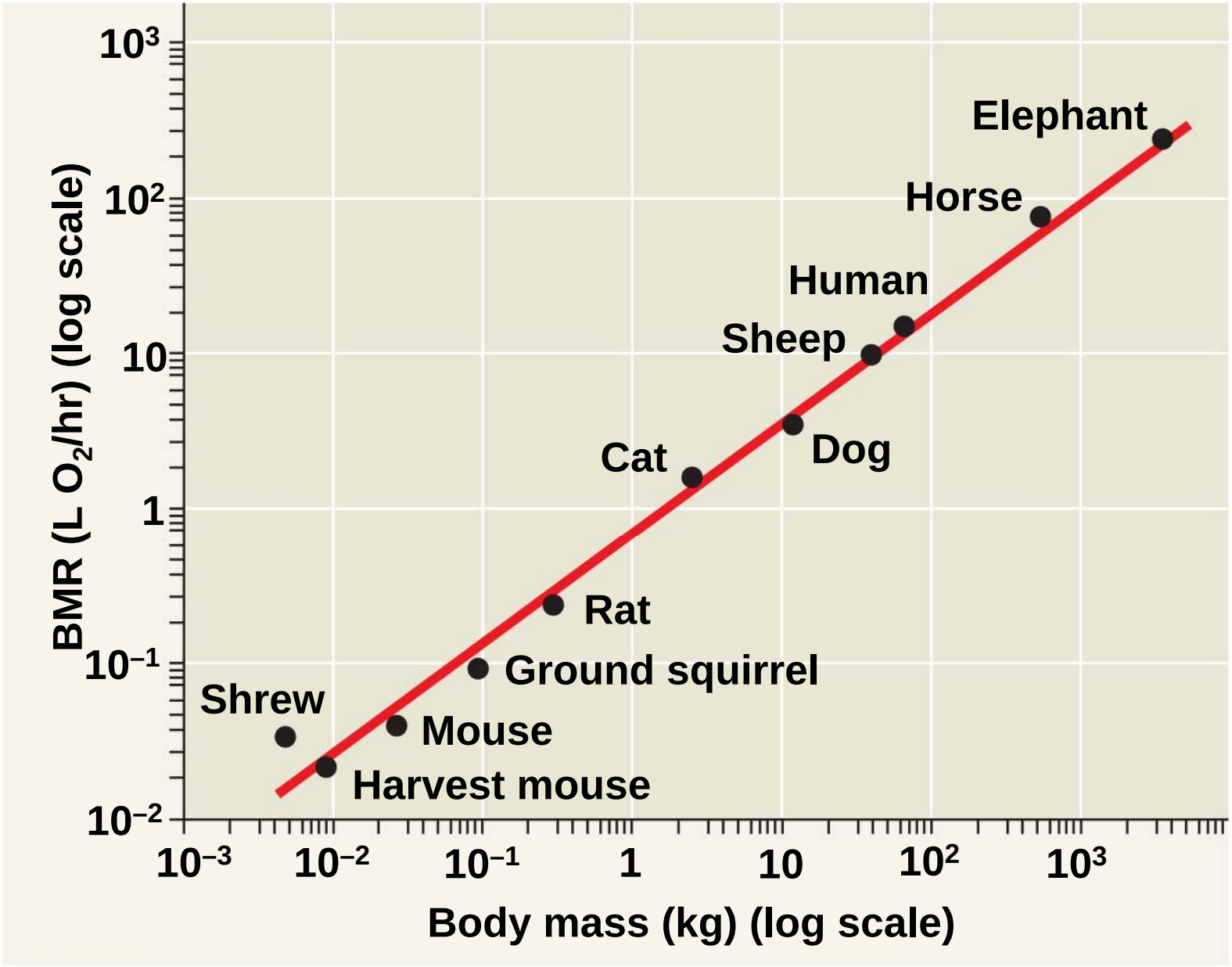


(a) Relationship of BMR to body size



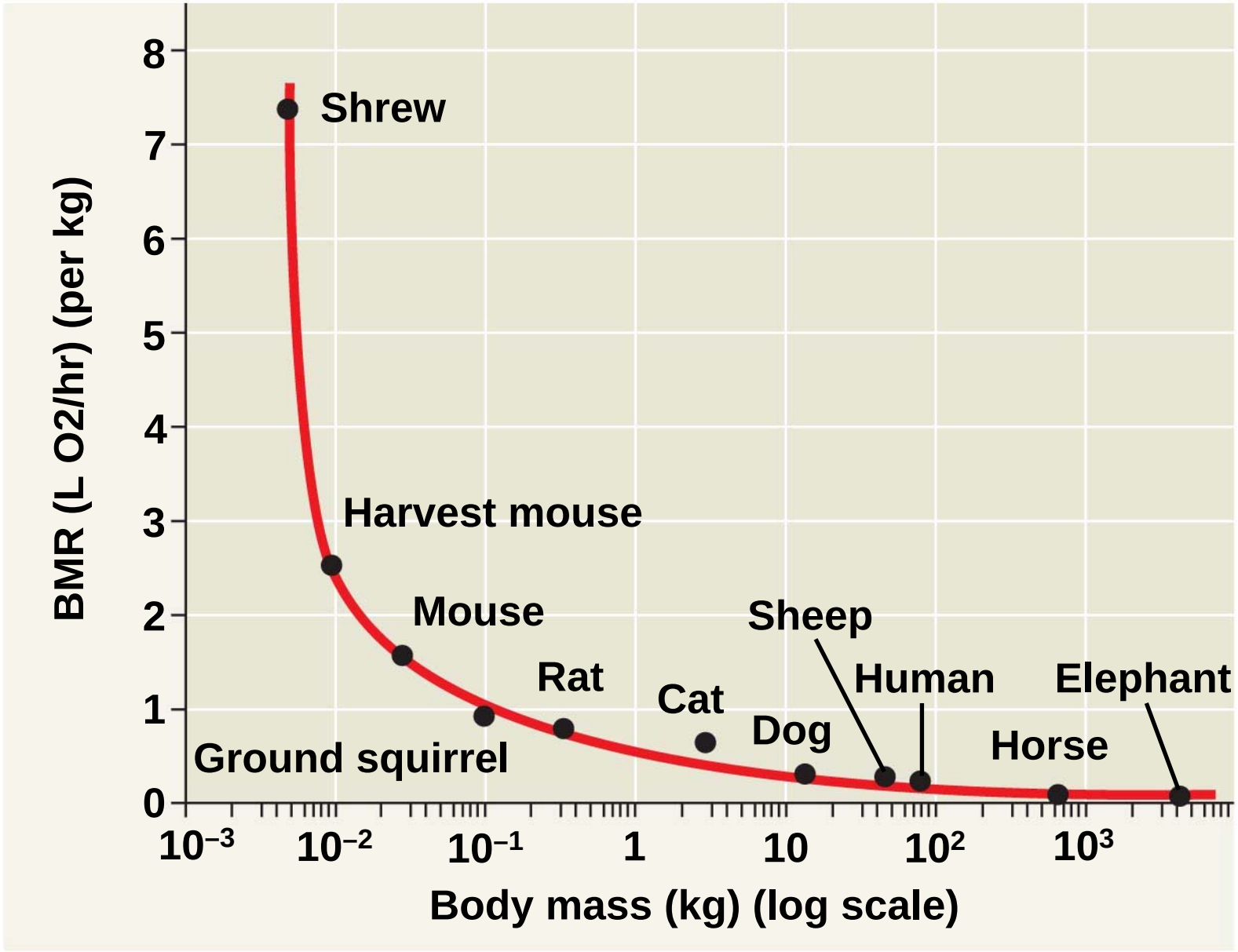
(b) Relationship of BMR per kilogram of body mass to body size

Fig. 40-19a



(a) Relationship of BMR to body size

Fig. 40-19b



(b) Relationship of BMR per kilogram of body mass to body size

Activity and Metabolic Rate

- Activity greatly affects metabolic rate for endotherms and ectotherms
- In general, the maximum metabolic rate an animal can sustain is inversely related to the duration of the activity

Energy Budgets

- Different species use energy and materials in food in different ways, depending on their environment
- Use of energy is partitioned to BMR (or SMR), activity, thermoregulation, growth, and reproduction

Fig. 40-20

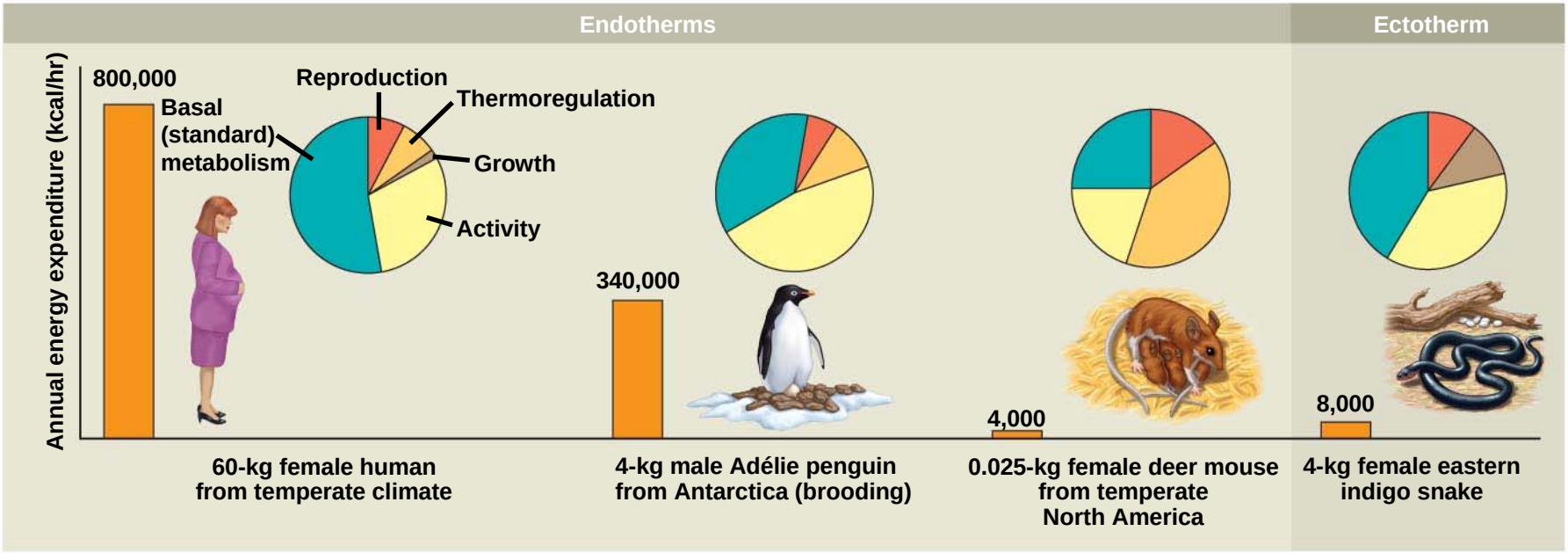


Fig. 40-20a

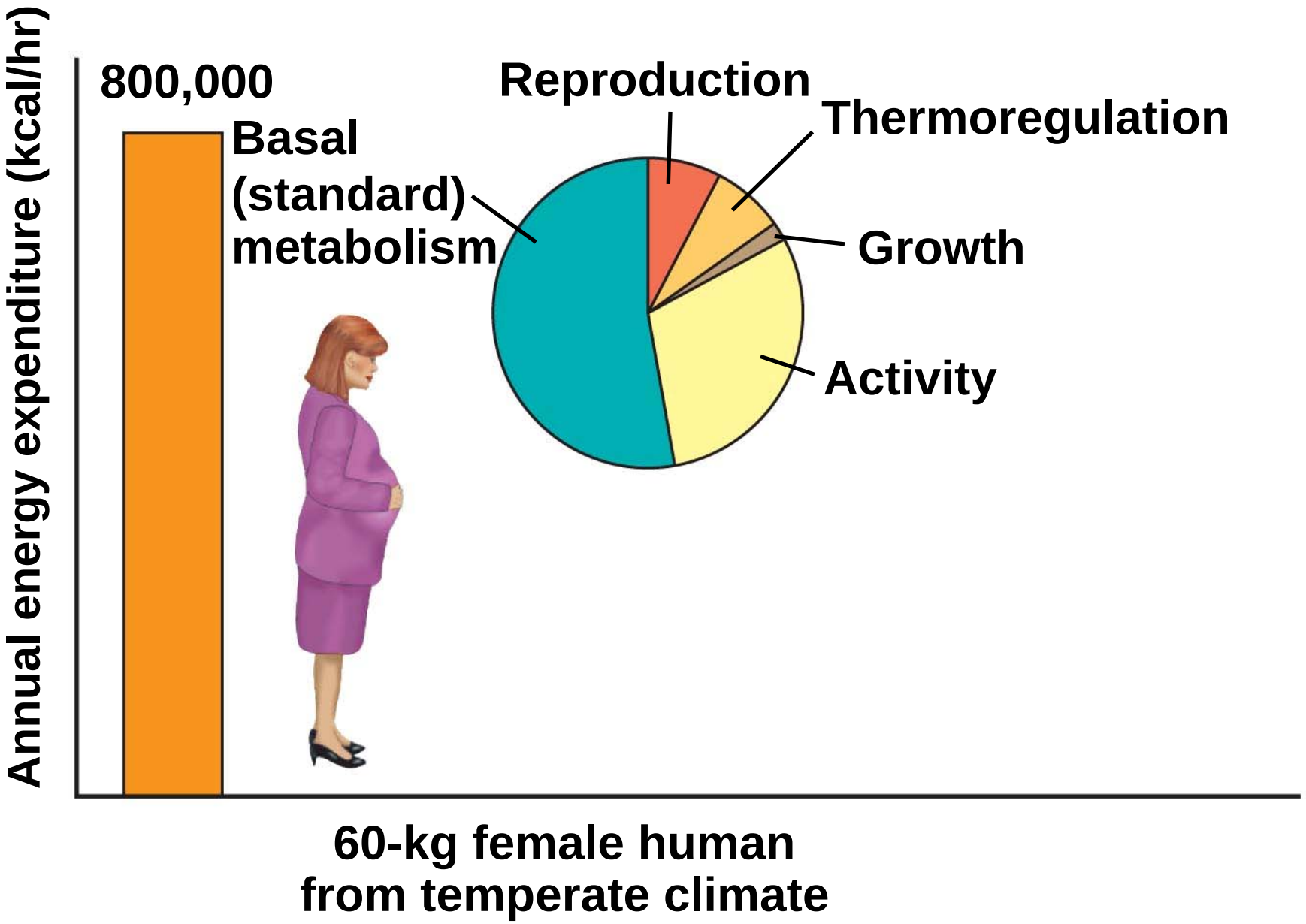


Fig. 40-20b

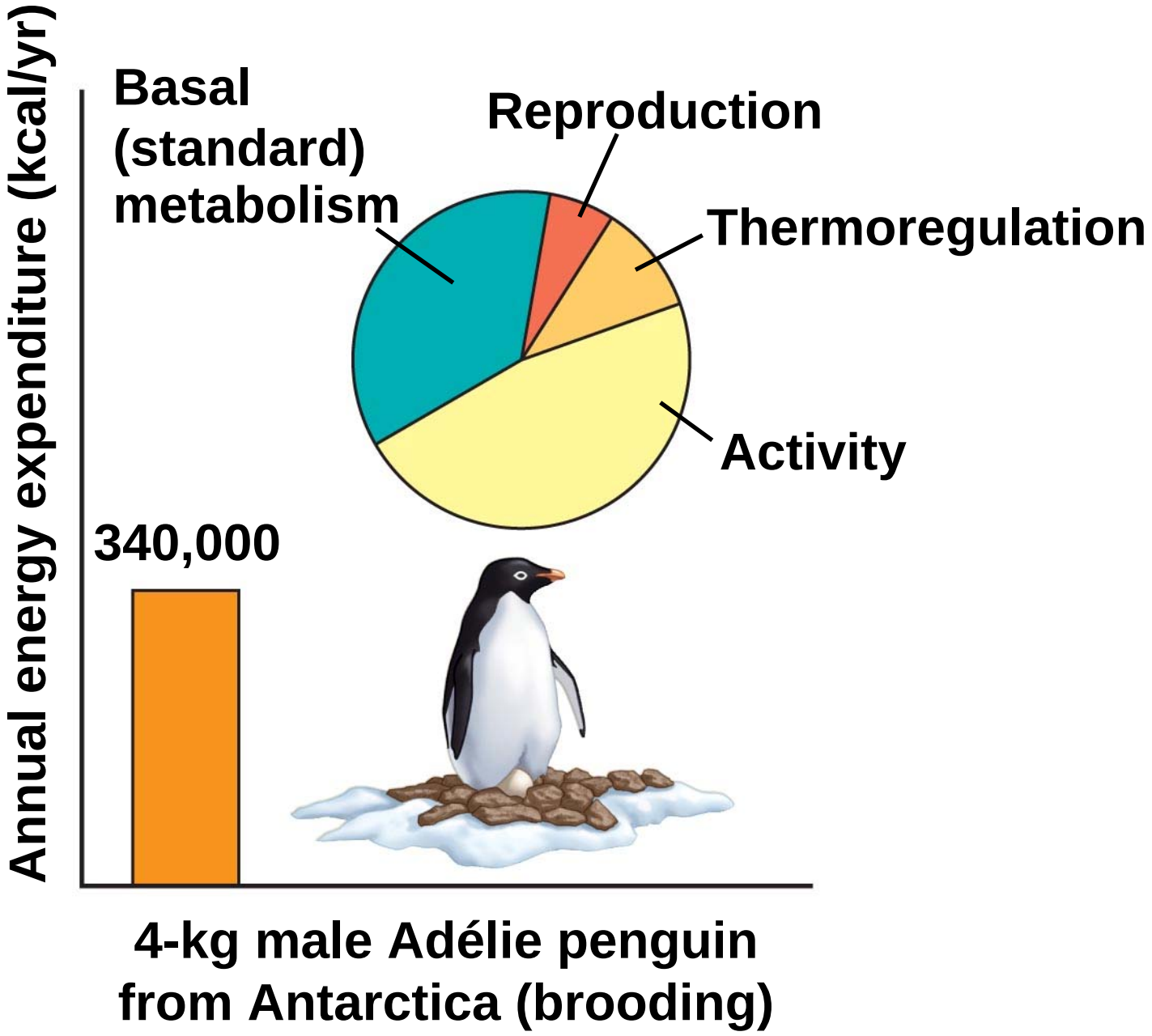


Fig. 40-20c

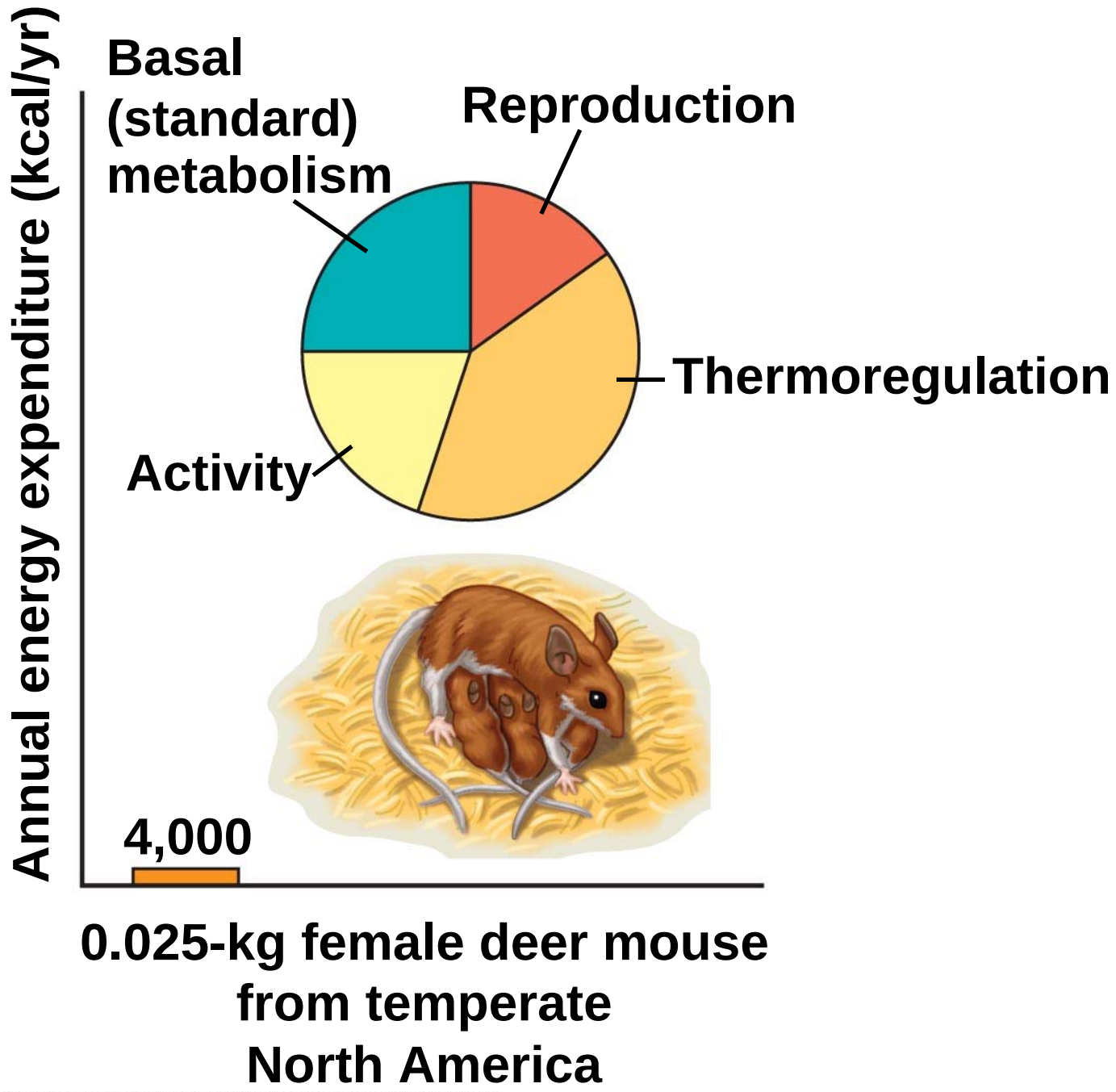
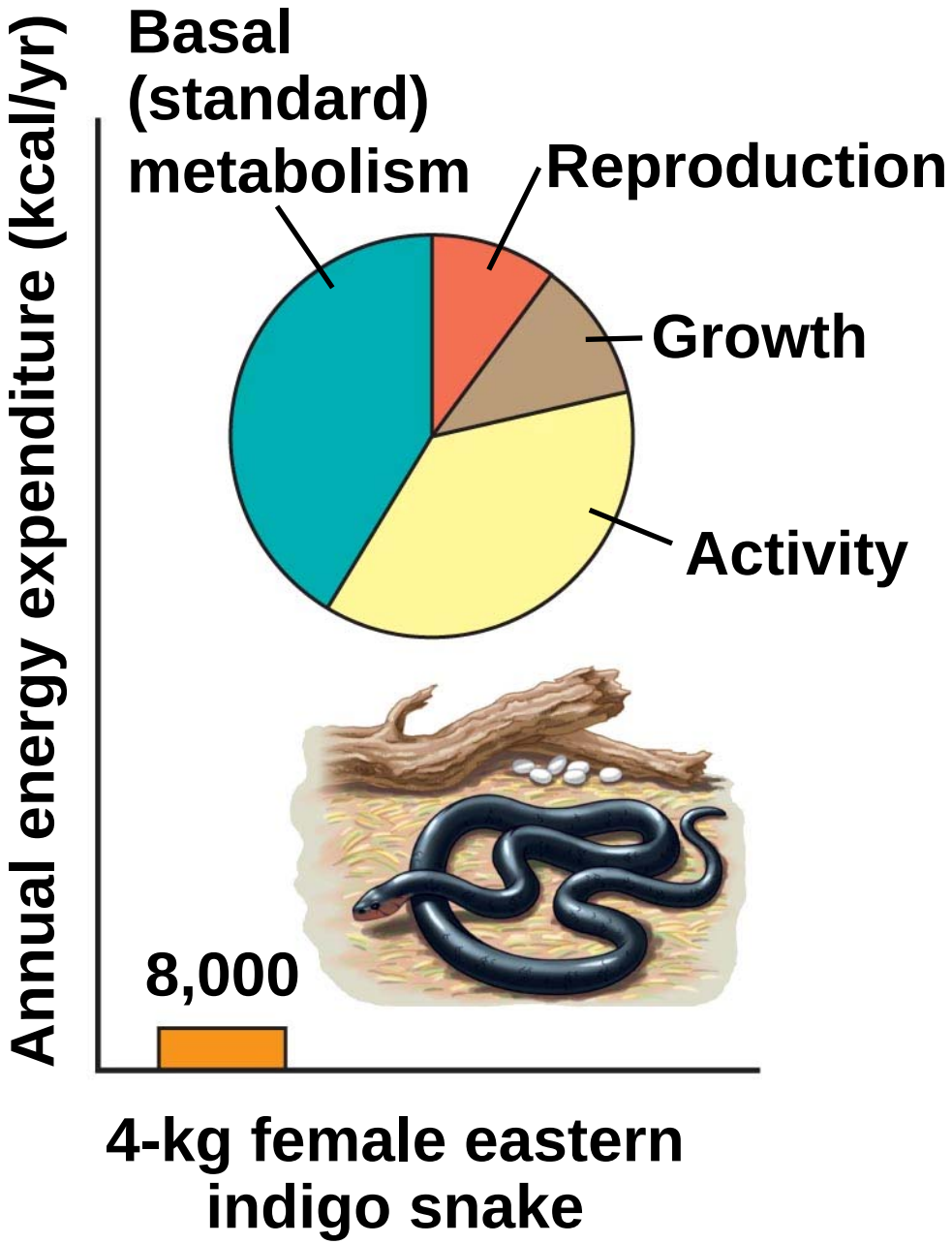


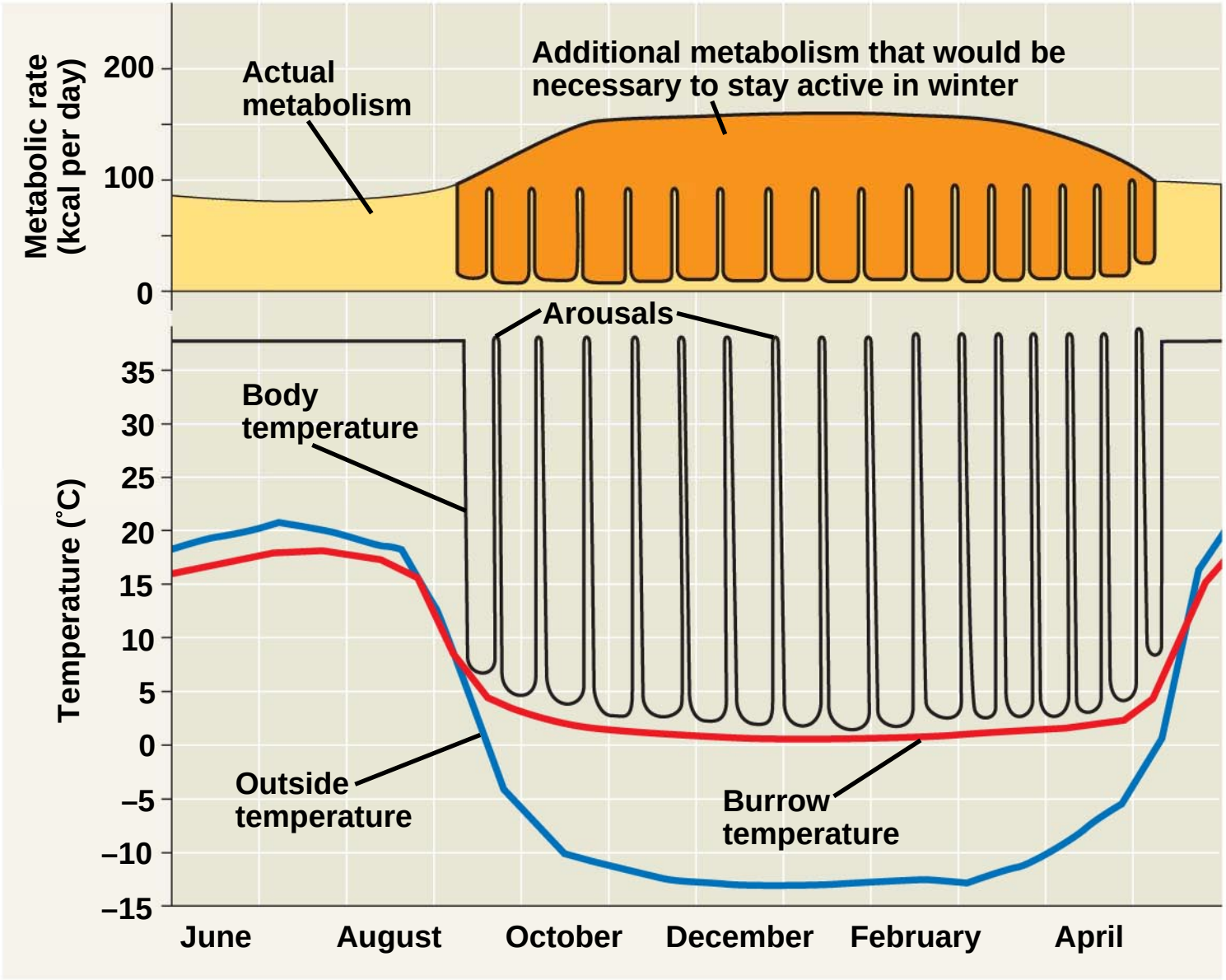
Fig. 40-20d



Torpor and Energy Conservation

- **Torpor** is a physiological state in which activity is low and metabolism decreases
- Torpor enables animals to save energy while avoiding difficult and dangerous conditions
- **Hibernation** is long-term torpor that is an adaptation to winter cold and food scarcity

Fig. 40-21



- *Estivation*, or summer torpor, enables animals to survive long periods of high temperatures and scarce water supplies
- Daily torpor is exhibited by many small mammals and birds and seems adapted to feeding patterns

Fig. 40-UN1

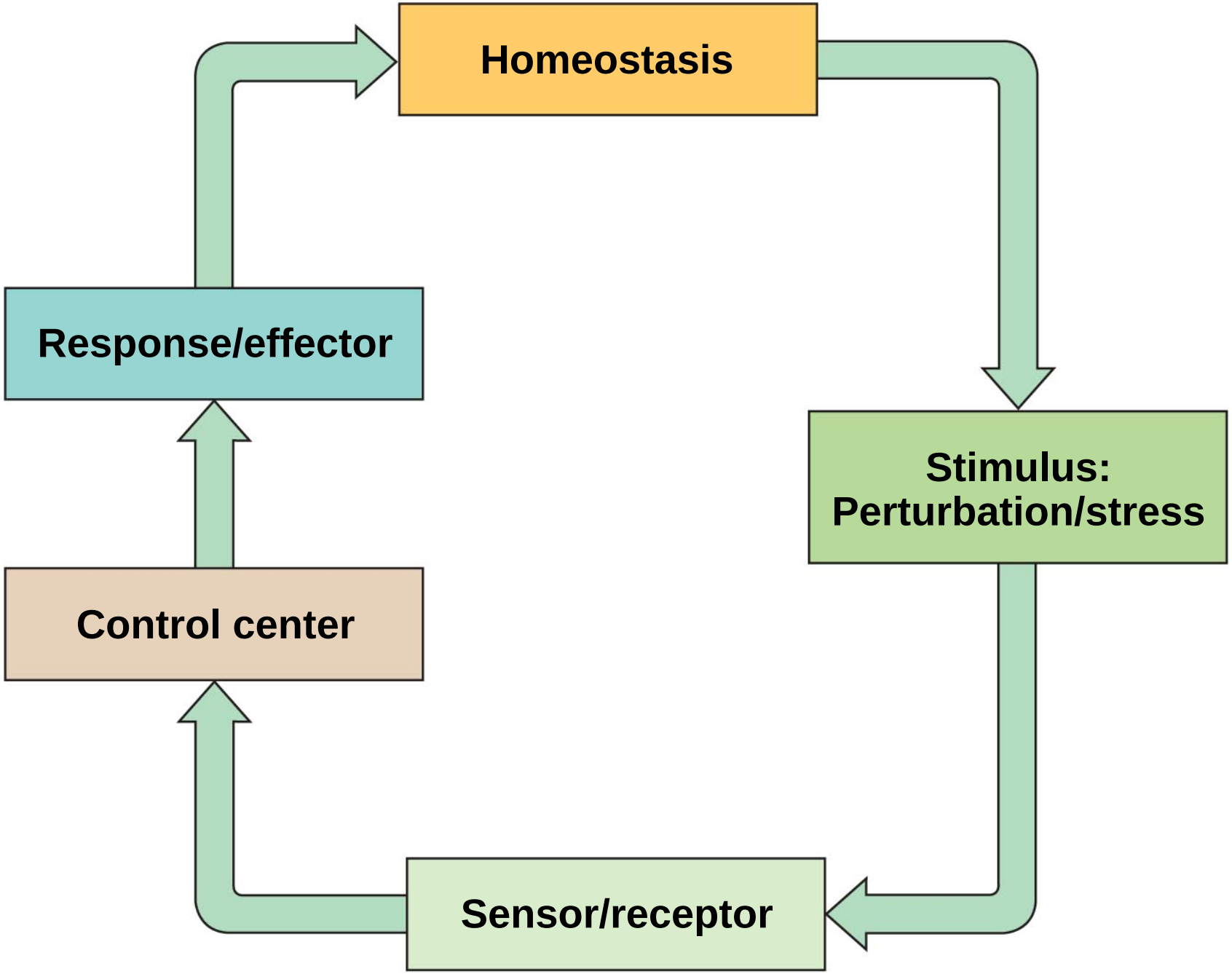
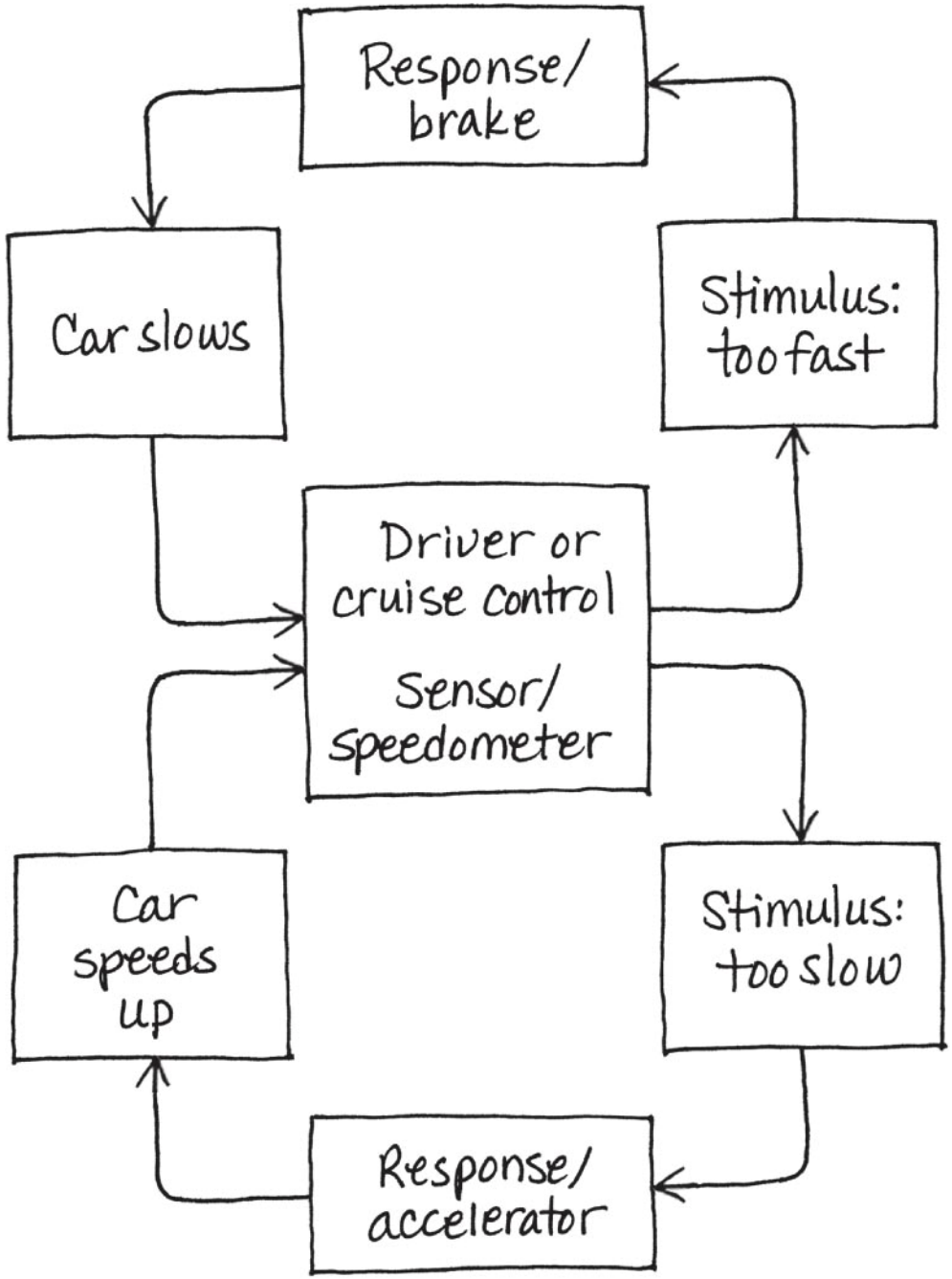


Fig. 40-UN2



You should now be able to:

1. Distinguish among the following sets of terms: collagenous, elastic, and reticular fibers; regulator and conformer; positive and negative feedback; basal and standard metabolic rates; torpor, hibernation, estivation, and daily torpor

2. Relate structure with function and identify diagrams of the following animal tissues: epithelial, connective tissue (six types), muscle tissue (three types), and nervous tissue

3. Compare and contrast the nervous and endocrine systems
4. Define thermoregulation and explain how endotherms and ectotherms manage their heat budgets
5. Describe how a countercurrent heat exchanger may function to retain heat within an animal body
6. Define bioenergetics and biosynthesis
7. Define metabolic rate and explain how it can be determined for animals